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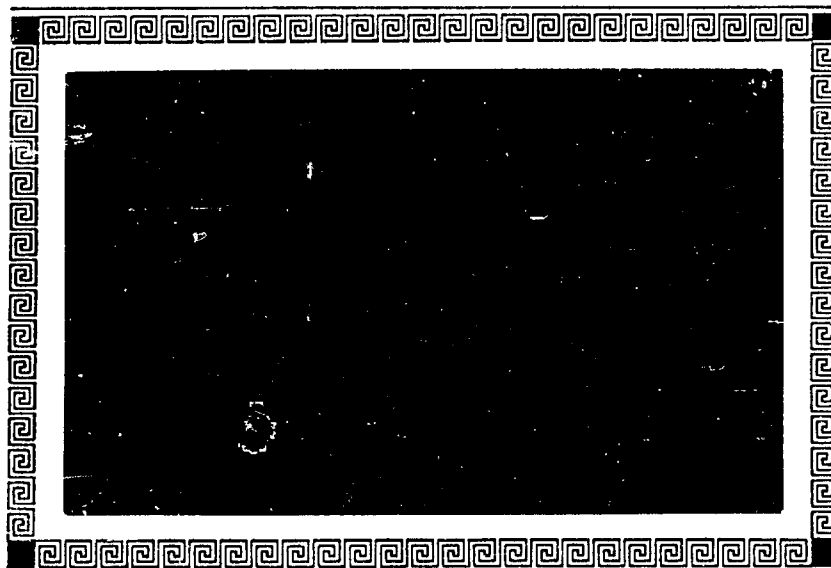


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THE FEASIBILITY OF A
RADIATION PROTECTED
COMMUNICATIONS REPAIR VEHICLE

by
T. W. Schwenke, N. J. Donnelly,
W. W. Hicks, and B. A. Frances

of

Technical Operations, Incorporated
Burlington, Massachusetts

15 January 1962

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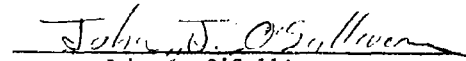
The MITRE Corporation is concerned with the survivability of the Air Force Command and Control Systems. It conducts studies in this general area in order to determine the levels at which various systems components fail and investigates various alleviating measures which may be employed to raise the levels of survivability.

One field of interest is the emergency repair of landline communications following a nuclear attack when large important land areas may be contaminated by fallout.

It is the purpose of this report to study the feasibility of employing radiation protected communications repair vehicles for shielding repair personnel from the effects of radiation while working and traveling to and from the work areas.

Chapter 1 introduces the communications repair problem and states the structure of the study. Chapter 2 contains an analysis of the major communications repair problems for which a communications repair vehicle must be designed. The following items are discussed: (1) the nature of the damage likely to occur during and after a nuclear attack, (2) the fallout environment in which the repair crew must make repairs, and (3) the tolerance of human beings to nuclear radiation. Chapter 3 describes the three different types of repair vehicles that are proposed: the first vehicle shelters a two-man crew only while transporting the crew to and from repair points, the second vehicle shelters a larger crew only while transporting the crew to and from repair points for team relay work on longer repair jobs, and the third vehicle shelters a two-man crew during both travel and actual repair work. The results of the sheltering calculations for these three vehicles are presented. Chapter 4 contains a brief analysis of the capabilities of the repair vehicles, and the conclusions and recommendations concerning these radiation protected repair vehicles are presented in the final chapter.

This document reports on the work performed for MITRE by Technical Operations Incorporated.


John D. O'Sullivan

ABSTRACT

This report presents the results of an initial study of the feasibility of a radiation protected communications repair vehicle. Chapter 1 introduces the communications repair problem and states the structure of the study. Chapter 2 contains an analysis of the major communications repair problems for which a communications repair vehicle must be designed. The following items are discussed: (1) the nature of the damage likely to occur during and after a nuclear attack, (2) the fallout environment in which the repair crew must make repairs, and (3) the tolerance of human beings to nuclear radiation. Chapter 3 describes the three different types of repair vehicles that are proposed: the first vehicle shelters a two-man crew only while transporting the crew to and from repair points, the second vehicle shelters a larger crew only while transporting the crew to and from repair points for team relay work on longer repair jobs, and the third vehicle shelters a two-man crew during both travel and actual repair work. The results of the sheltering calculations for these three vehicles are presented. Chapter 4 contains a brief analysis of the capabilities of the repair vehicles, and the conclusions and recommendations concerning these radiation protected repair vehicles are presented in the final chapter.

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- SR-18, "On the Application of the Theory of Locking Media to Ground Shock Phenomena," M. G. Salvadori, R. Skalak, and P. Weidlinger.
- SR-19, "Theoretical Studies on Ground Shock Phenomena," M. L. Baron, H. H. Bleich, and P. Weidlinger.
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- SR-26, "A Submersible Emergency Command Control Communication Barge," S. S. Murray.
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- SR-34, "Soft Filled Liners for Rock Tunnels in Very High Pressure Environments," Newmark, Hansen and Associates.
- SR-37, "An Experimental Study of Cavity Collapse Mechanism," Lewis T. Assini, John K. Hawley, and C. C. Mow.
- SR-39, "The Feasibility of a Radiation Protected Communications Repair Vehicle," T. W. Schwenke, N. J. Donnelly, W. W. Hicks, and B. A. Frances.

CHAPTER 1

INTRODUCTION

This report summarizes the initial investigations carried out by Technical Operations, Incorporated, for The MITRE Corporation under Contract M20459. The study was concerned with the feasibility of a communications repair vehicle that would afford radiation protection to a repair crew while in transit to and from a damaged area and possibly while the crew performs its tasks. Studies were confined to communications repairs of a minor nature, and emphasis was placed on the use of expedient rather than permanent repairs whenever possible, because of the importance of speed in restoring vital communications links. Only military and governmental communications needs were considered; the time period chosen for the operational use of the repair vehicle is 1965-1970.

BACKGROUND

In the event of a nuclear attack upon the United States, it is of the utmost importance that communications in the military command and control networks be maintained so that the country's offensive and defensive forces may be alerted, released, and controlled effectively to combat the attack. Communications vulnerability studies, however, have demonstrated the likelihood that portions of the communications network will be rendered inoperative because of various types of damage ranging from major destruction of the network to minor destruction that is repairable within a reasonable length of time. Major damage would consist of the destruction of a network or that portion of a network situated near a weapon burst point, while minor damage would consist of small breaks in the network links, either in the cables and telephone lines themselves or in the stations and radio towers that control the networks. In addition, ordinary equipment failures such as those that occur during peacetime are included in this study, for these routine repairs become vital during an attack, and at the same time their execution is hampered by fallout and debris.

Vital communications might be restored by rerouting circuits over the lines that survive an attack or by using back-up communications systems when available. In some cases, however, it may be possible to repair the damage and restore the existing circuits in time to be of considerable value if repair vehicles and crews can be sent

quickly to the damaged point. Because the damage could occur in an area contaminated by fallout, a repair vehicle must be designed and operated in such a manner that its crew can make the necessary repairs without receiving whole body radiation doses in excess of a specified maximum.

The enemy has available a wide variety of strategies that might be employed in a war against us, and no one knows with certainty what the attack plans are or what they may be in the future. We can conduct studies to determine what constitutes good enemy strategy, however, and then plan accordingly. Studies on enemy strategy have indicated that it is wise in some cases for the enemy to allocate more than one weapon to important targets in the United States, while in other cases it is sufficient to allocate only one bomb. If the enemy attack is well designed, it is reasonable to expect considerable variation in the radiation levels of various areas within this country during and after attack.

The intensity of fallout radiation in an area and accordingly the amount of radiation protection required for a repair vehicle in that area depend on the density of targets in the vicinity and on the type and number of weapons directed at each target. There may be areas having approximately the same damage to communications but with quite different fallout levels. Consequently, a repair vehicle that is feasible for some areas may be too lightly protected for operation in other areas.

Radioactivity decays with time, and therefore the feasibility of using repair vehicles is also a function of the size of the time increment between the bomb burst and the possible commencement of repair activity. At some time after the attack, the lightly protected repair vehicles will be able to go into areas where previously the radiation levels were too high. Unfortunately, however, the urgency of the need for communications repair is greatest during and immediately after attack, before the radioactivity has diminished greatly.

GENERAL STRUCTURE OF THE STUDY

This study considers a variety of ground and airborne communications repair vehicles that are capable of transporting, sheltering, and assisting repair personnel who are to work in contaminated areas. The effort is divided into two phases:

Phase I: Analysis of the Environment in Which the Vehicle Must Operate

This phase consists of two parts: first, an analysis of the types and extent of the communications damage to be repaired, and second, an investigation of the effects of radioactive fallout on the environment.

Phase II: Specification and Preliminary Design of a Communications Repair Vehicle

Phase II also consists of two parts: first, a study of the technical requirements of a radiation protected communications repair vehicle with the presentation of various specific ground, airborne, and combination ground-airborne designs, and second, an investigation of the operational effectiveness of the vehicles hypothesized.

In addition, the following ground rules have been established for this study:

1. This study is concerned with repairs to network links¹ that can be accomplished by a team of repairmen operating from a single vehicle.² These repairs are to be carried out in as short a time as possible and frequently consist of temporary rather than permanent measures. Emphasis is on repairing critical circuits rather than on restoring whole-system operation.
2. The emphasis of the study is on technical feasibility rather than on costs and economic feasibility.
3. All vehicles are presumed to originate from sheltered garages or from garages located at points that are remote from bomb blasts and intense radiation.
4. The location and the extent of the damage have been already established³ and are known by the repair crew.
5. Repairs to underwater cable installations are not to be considered at this time.

¹ Network links are defined as those parts of the communications network that serve to connect or link the various communications centers or terminals, excluding the communications centers themselves.

² In some cases, it may be necessary to concentrate teams from several vehicles.

³ Many problems will be encountered in locating and evaluating the damage and in scheduling emergency repair operations. However, this limitation was necessitated by the amount of effort to be expended on this study as specified by The MITRE Corporation.

CHAPTER 2

THE COMMUNICATIONS REPAIR PROBLEM

The first objective of this study is twofold: to determine the nature of the communications network damage for which the repair vehicles and crews are to be dispatched, and to determine the expected levels of radiation in the areas where damage is likely to occur. The nature of the damage must be known before one can estimate the length of time needed to make the repairs. The levels of radiation must be known, since the vehicles are required to operate in a fallout environment. Together, the repair time plus the radiation level will give, in each instance, the measure for the total time radiation dose to which the vehicles and crews are exposed during the repair operation.

NETWORK DAMAGE

Damage to communication network links during the critical period at the time of and following the nuclear attack can be grouped into three main categories:

1. Failures brought about by nuclear bomb detonations
2. Failures that ordinarily occur under peacetime operations
3. Failures brought about by sabotage.

NUCLEAR DETONATIONS

Nuclear bomb detonations produce blast waves that cause extensive damage to nearby structures. The loading or drag forces of the wind following the passage of a blast wave bring about damage to microwave radio, UHF radio, television towers, telephone lines and poles, and suspended cables. The peak overpressure associated with the blast wave can collapse buildings by compression at the same time that wind loadings are bringing down poles and towers. Direct thermal radiation from the detonation is likely to start many fires in structures and materials located in the area surrounding ground zero. Both the direct thermal radiation and the heat and structure collapse brought about by induced fires can disrupt nearby communication lines.

The bomb will destroy any buried cable that runs through the crater area. Outside the crater area, cable breaks and other equipment damage will be brought about

by the ground shock wave with its accompanying shifting and movement of the ground.

PEACETIME FAILURES AND SABOTAGE

In addition to the damage from bomb detonations, consideration must be given to network breaks occurring as a result of other causes, such as damage from storms, fires, and floods, or, in a state of war, from sabotage. Random breaks due to ordinary wear, short and open circuits, and tube failure could also occur.

Table 1 illustrates the kinds of damage and malfunction in communication links that a communications repair vehicle should be capable of repairing. Data are presented on (1) the nature of the damage, (2) the cause of the damage, (3) the nature of the applicable repair, and (4) the requirements imposed on the repair crew.

For the purposes of analysis, a repair area may be defined as the area within a circle centered at ground zero having a radius just large enough so that all bomb-induced damage to communications links will fall within it. Table 1 and the report, "The Effects of Nuclear Weapons,"¹ give the statistics by which the radius of the repair area can be determined.

THE FALLOUT ENVIRONMENT

In an attack on the continental United States, it is expected that the enemy would strive for the destruction of our installations and equipment through the use of surface bursts of nuclear weapons rather than air bursts and that these nuclear weapons would be of megaton size. Although data obtained from explosions of large nuclear weapons are incomplete, many facts are known and will be reviewed briefly.

BASIC MECHANISM

When a nuclear weapon is exploded on the ground, a crater is formed under the detonation, and the displaced earth is broken up into small particles due to the violent

¹U.S. Government Printing Office, "The Effects of Nuclear Weapons" (Washington, D.C.: 1957) p. 253.

TABLE 1

COMMUNICATIONS NETWORK LINKS — DAMAGE AND REPAIR TABULATION

NETWORK ELEMENTS	NATURE OF DAMAGE (in Order of Seriousness)	FACTORS LIKELY TO CAUSE DAMAGE	NATURE OF REPAIR	HOURS TO REPAIR	PERSONNEL NEEDED	VEHICLES NEEDED
MICROWAVE RADIO TOWER AND RELATED ELECTRONIC EQUIPMENT	Electronic equipment malfunction and maintenance	Factors that arise in normal day-to-day operation, such as failure, open, wearout, tube failure, and the like	Malfunction of electronic equipment requires the service of a technician, to be repaired. Scheduled or preventive maintenance is also considered in this category. The technician will, for some tasks, conduct his operation inside a hut that houses a good portion of the electronic equipment, and, in others, on the tower itself	1 1/2 to 2	1 or 2	Category A* Utility repair vehicle
	Reflector plate twisted beyond maximum permissible — 2 1/2 to 3 degrees	Wind velocity of 120 to 130 mph, corresponding to an overpressure of 3 1/2 to 4 psi	Reflector plate realignment requires a man working on top of the tower and a minimum of one man below, to assist in calibrating the realignment	1 1/2 to 2	2 to 3	Category B* Utility vehicle with utility repair equipment
	Major reflector plate damage through torsion and buckling. Damage to supporting structure such as reflector dish couplings. Cables from the reflector dish to the antenna may be also damaged at this point. Existing structures (flats) that house the electronic equipment are likely to suffer some damage if not constructed of reinforced concrete	Wind velocity of 130 to 140 mph, causing damage, through loadings, to reflector plate, dishes, supporting structure, and cable. The corresponding overpressure of 4 to 4 1/2 psi causes damage to the flat through crushing action	Major reflector plate damage requires that the construction crew make necessary structural repairs to the damaged tower and replace the reflector plate and dishes. Electronic technicians will take over the antenna. If the flat is damaged, some forms of electronic equipment may need to be repaired	6 to 12 depending on extent of structural damage	5 to 10	Category B* Ladder truck with utility repair equipment (welding equipment and rigging)
	Tower buckled. Extensive structural damage throughout. Reflector plate and antenna damaged. Cables possibly damaged	Wind velocity of 140 to 150 mph, corresponding to an overpressure of approximately 4 1/2 to 5 psi	Extensive, major rebuilding and repairs are necessary. Most likely a new tower and associated equipment would be constructed on site. The urgency of restoration may make it advantageous to press one or more mobile temporary towers into service to carry over pending permanent tower is being replaced. This may be cases of extensive damage, be used for the duration of the fallout threat.	Over 24	5 to 10	Category B* Derrick, ladder truck with heavy repair equipment
	Tower demolished and related electronic equipment is but put out of commission	Wind velocity in excess of 150 mph, corresponding to an overpressure in excess of 5 psi	A new tower and associated equipment would be constructed A temporary, transportable, truck-mounted tower and associated equipment would be placed in service	Under 4, once replacement is in place	3 to 4	Category A* Truck-mounted tower utility truck

Vehicle Classification

Vehicle Category	Gross Weight (lbs)
A	under 5,000
B	5,000-10,000
C	over 10,000

TABLE 1 (Cont'd.)

NETWORK ELEMENTS	NATURE OF DAMAGE (in Order of Seriousness)	FACTORS LIKELY TO CAUSE DAMAGE	NATURE OF REPAIR	HOURS TO REPAIR	PERSONNEL NEEDED	VEHICLE(S) NEEDED
VHF RADIO AND TELEVISION TOWERS AND RELATED ELECTRONIC EQUIPMENT	Unguyed tower blown down and guyed towers partially buckled but held by guy lines. Ineffective for transmission	Winds of around 100 to 140 mph corresponding to an overpressure of 3 to 4-1/2 psi	Extensive, major rebuilding and repairs necessary. Tower and associated equipment probably would be replaced	12 to over 24	4 to 8	Categories B and C, ladder truck, with heavy repair equipment
	Both unguyed and guyed towers demolished. Electronic but and housed equipment probably also destroyed	Winds of around 140 to 160 mph, corresponding to an overpressure of 4-1/2 to 5-1/2 psi	Placing of temporary, transportable, truck-mounted tower and equipment in service	Under 4	3 to 4	Categories A and C, truck-mounted tower, mounted tower, Utility truck
		Winds of around 140 to 160 mph, corresponding to an overpressure of 4-1/2 to 5-1/2 psi	New tower and associated equipment would be installed	Over 24	4 to 8	Categories B and C, derrick, truck(s), with heavy repair equipment
OPEN AND MULTIPLE AERIAL- SUSPENDED LINE WIRES AND POLES	Wire or cable service failure	These service failures are those that arise during periods of operation. They are not part of a random failure. These failures include shorts, opens, and service failures arising from electrocution, falling branches, etc.	Placing of temporary, transportable, truck-mounted tower and equipment in service	Under 4	3 to 4	Categories A and C, truck-mounted tower, Utility truck
	Wire or cable break	Breaks due to falling branches, falling trees, other structures. Overpressure of 1 to 2 psi	A repair crew would be dispatched to repair either the broken cable or the broken support. The length of cable. This generally will be performed by a repairman who has either climbed to the top of a pole or is brought to the break by means of a ladder truck or a controllable boom-supported bucket truck. The repair crew would either splice the broken cable or replace the length between two poles. A quick fix would not necessarily require that the cable be placed in permanent suspension position. If only temporarily, lie on ground.	2 to 4	2	Categories A or B, Utility truck, or ladder truck, or boom-supported bucket truck, with splicing equipment and cable fix (b)
	Poles snapped. Probable attendant wire and cable damage	Transverse winds in excess of 90 mph, corresponding to an overpressure in excess of 2-1/2 psi	With poles snapped and down, any line break would be temporarily spliced, or the cable length would be temporarily replaced. The broken cable would be tied or spliced around damaged portion of network. Only later would the individual poles (and attendant wires and cables) be replaced.	4 to 6	2 to 4	as above, with splicing equipment and cable
				6 to 24	4 to 8	Categories A and/or B

Vehicle Classification

Vehicle Category	Gross Weight (lb)
A	under 5,000
B	5,000-10,000
C	over 10,000

TABLE 1 (Cont'd.)

NETWORK ELEMENTS	NATURE OF DAMAGE (in Order of Seriousness)	FACTORS LIKELY TO CAUSE DAMAGE	NATURE OF REPAIR	HOURS TO REPAIR	PERSONNEL NEEDED	VEHICLES NEEDED
BURIED CABLE AND WIRE	Service malfunction	Random failures and malfunctions (e.g., insulation, deterioration leading to electrolysis, shorting, and resistor failure)	Repair of cable or attendant equipment on the spot	4 to 8	2	Category A ^a Splicing equipment Digging equipment
	Cable partially or completely broken, cable junctions ruptured	Cratering by bomb. Detonation or shock-induced motion in ground. Non-weapon causes would be motion in the ground induced by earthquakes as well as landslides	The quickest repair would be that of splicing in a new length of cable. There is no need at this time to bury the cable.	2 to 24, depending on the number of conductors to be spliced	2 to 4	Category B ^a
UNDER-GROUND CABLE IN CONDUIT	Service malfunction	Random failures and malfunctions	If one or two pairs of wires need repairing, the length of cable having the malfunction is drawn back to a manhole, the repair is made, and the cables replaced. If more extensive repairs are needed, it is advisable, in view of the shortage of time, to span a new cable above ground between manholes. A provision is made in the contract for the repair of cables in the conduit can be made at a later date. Attendant equipment repaired or replaced as necessary. New cable spanned above ground across the break.	3 to 29, depending on the number of conductors to be spliced	2 to 4	Category A or B ^a Pump may be needed
	Cable partially or completely broken	Cratering by bomb. Detonation or shock-induced motion in ground. Non-weapon causes would be motion in the ground induced by earthquakes as well as landslides.		2 to 24, depending on the number of conductors to be spliced	2 to 4	Category B ^a

* Vehicle Classification

Vehicle Category	Gross Weight (lbs)
A	under 5,000
B	5,000-10,000
C	over 10,000

motions within the fireball. These particles become radioactive as a result of the condensation and collection of the fission products of the bomb. Also, these particles rise with the fireball and become distributed throughout the mushroom-shaped cloud. The cloud appears to stabilize a short time after the burst (in about ten minutes for a 10-MT weapon), after which time the gravitational and meteorological forces start to dominate the behavior of the cloud particles. As the particles fall, they are influenced by winds at different altitudes. The heavier particles fall near ground zero while the lighter ones are distributed at various distances downwind. The radioactive particles that fall on the ground are responsible for the contamination in downwind areas and are referred to as fallout. In speaking of fallout, one can also speak of fallout levels; this term refers to the amount of contamination at any point caused by the particles that fall at that point (or in the vicinity of that point).

FACTORS INFLUENCING FALLOUT

The final position on the ground of the radioactive particles from a single detonation (and the resultant fallout level at any point) is determined by a large number of physical parameters, the most important of which are:

1. Weapon size
2. Particle size distribution in the cloud
3. Wind field from the top of the cloud to the ground
4. Radioactivity associated with the different particle sizes.

The reasons why these factors influence fallout are discussed in Appendix A of this report, but it should be kept in mind that these factors are not independent, but are interrelated in their influence upon fallout.

FALLOUT MODEL

For this study, a mathematical model² of the fallout process was used to describe the fallout environment. This model, coupled with representative prevailing wind data, was used to produce geographic plots of isodose-rate contours, as illustrated in Figure 1.

²This model is discussed briefly in Appendix A.

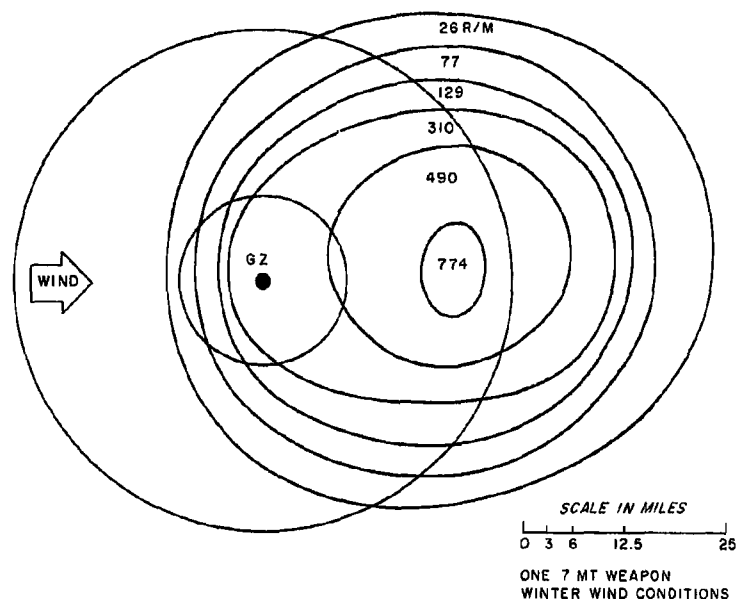


Figure 1. Isodose-Rate Contours at One Hour After Burst

Presentation of the Fallout Data in a Form Suitable for Operations Analysis of a Communications Repair Vehicle

As explained above, radioactivity resulting from a nuclear attack will be distributed over the country under the action of winds. While particles are falling downward from the bomb cloud and after they have arrived, particle radioactivity will diminish in accordance with known radioactivity decay rates. It is to be expected that immediately after a nuclear detonation a relatively small area around ground zero will be exposed to a high radiation intensity (dose rate), and in subsequent time periods large areas downwind from ground zero will be exposed to lesser intensities. Since a measure of radiation field intensity (roentgens per hour) is basic to all calculations relating to human endurance, data on field intensity with respect to time were sought. The fallout model mentioned previously was used to determine geographical isodose-rate contours, which are summarized in graphs of a form directly useful for operational effectiveness evaluations. These graphs show the per cent of a specified geographical area that is exposed to a dose rate of less than R roentgens per hour as a function of time after detonation.

A measure of the operational effectiveness of alternative repair vehicles is the number of repairs of some representative type that they might be able to accomplish. Unshielded vehicles would be restricted from operating in large areas because their operators and other personnel would receive unacceptably large doses. Vehicles with large shelter factors could operate in more of the fallout area than the less well-sheltered vehicles. When comparing alternate vehicles, one must hold constant both the maximum acceptable human dose and the nature of the repairs to be accomplished, while allowing other factors to vary. One can take the amount of area in which a vehicle can operate as a first approximation of the number of repair tasks which that vehicle can attempt.

The operational effectiveness for repair vehicles can be estimated when two vehicle parameters are known. These parameters are: (1) the effective vehicle shelter factor (attenuation), and (2) the effective duration of exposure (a composite of repair time and travel time).

HUMAN TOLERANCE TO NUCLEAR RADIATION³

Human tolerance to nuclear radiation is a function of: (1) the total absorbed dose, (2) the rate of absorption, and (3) the region and area of body exposure. The genetic effects of nuclear radiation are cumulative and depend largely on the total dose received. The remaining biological effects are also influenced by the rate of absorption, and they decrease with decreasing rates of exposure. It is well known that the human body is accustomed to recovering from exposure to radiation from natural sources received continuously over a long period of time: the average human being receives a total of 10 to 12 roentgens of nuclear radiation during a lifetime. The importance of the dose rate lies in the fact that, if the dose rate is not too large, the body can partially recover from the radiation injury while still being exposed. Areas of the body may be classified as to their sensitivity to radiation as follows: (1) most sensitive — lymphoid tissue, bone marrow, spleen, reproductive organs, and gastro-intestinal tract, (2) intermediately sensitive — skin, lungs, kidney, and liver, (3) least sensitive — muscle and full-grown bones. Restricted exposure results in less severe

³U. S. Government Printing Office, "The Effects of Nuclear Weapons," (Washington, D. C. : 1957) Chapter 11.

injury because of the ability of the unexposed sections of the body to contribute to the recovery of the injured areas.

In this study, a distinction is also made between the long-range effects of nuclear radiation, such as cataracts, leukemia, and genetic mutations, and the effects occurring within the one- to two-day period after dose reception.

Tables 2, 3, and 4 summarize the data on human tolerance to radiation. A more detailed discussion will be found in Appendix A.

Exposure Limits for Repair Missions

If the repair of communications facilities is to be effected as rapidly as possible after the attack, it is inevitable that some personnel will be exposed to high intensity radiation during the performance of their duties. It is imperative that the accumulated dose be kept below the lethal level, but sufficient latitude exists over the range of permissible doses to allow a trade-off between the essential repairs that must be accomplished and the dosage acquired by the personnel engaged in these tasks. For purposes of this study we shall be concerned with the nuclear radiation effects occurring from acute whole-body exposure to doses in the range of 25-250 roentgens. The lower limit of 25 roentgens is the approximate threshold below which acute exposure will produce no detectable clinical effects. Survival, while possible, is by no means certain with whole-body exposure in doses greater than 250 roentgens.

For this report, we have chosen the upper limit of 250 roentgens as the maximum allowable dose to be considered for repair personnel. This choice was based primarily on a consideration of short-term effects, because it was felt that, until survival was insured for the first few days after the attack, the long-term effects were of secondary importance. Whole-body exposure to a radiation dose in the range of 100-250 roentgens will probably not prove fatal, and the most disabling symptoms will appear during the first day of exposure. If the individual is able to overcome possible nausea and vomiting, he should be able to carry on his usual duties during the one- to two-day period within which the important repair effort is needed.

TABLE 2
EXPECTED EFFECTS OF ACUTE WHOLE-BODY RADIATION DOSES⁴

ACUTE DOSE . (ROENTGENS)	EFFECTS ON THE HUMAN BODY
0 to 50	No obvious effect, except possibly minor blood changes
80 to 120	Vomiting and nausea for about 1 day in 5 to 10 per cent of exposed personnel. Fatigue but no serious disability.
130 to 170	Vomiting and nausea for about 1 day, followed by other symptoms of radiation sickness in about 25 per cent of personnel. No deaths anticipated.
180 to 220	Vomiting and nausea for about 1 day, followed by other symptoms of radiation sickness in about 50 per cent of personnel. No deaths anticipated.
270 to 330	Vomiting and nausea in nearly all personnel on first day, followed by other symptoms of radiation sickness. About 20 per cent deaths within 2 to 6 weeks after exposure; survivors convalescent for about 3 months.
400 to 500	Vomiting and nausea in all personnel on first day, followed by other symptoms of radiation sickness. About 50 per cent deaths within 1 month; survivors convalescent for about 6 months.
550 to 750	Vomiting and nausea in all personnel within 4 hours from exposure, followed by other symptoms of radiation sickness. Up to 100 per cent deaths; a few survivors convalescent for about 6 months.
1000	Vomiting and nausea in all personnel within 1 to 2 hours. Probably no survivors from radiation sickness.
5000	Incapacitation almost immediately. All personnel will be fatalities within 1 week.

⁴Ibid., p. 471.

TABLE 3

SUMMARY OF CLINICAL SYMPTOMS OF RADIATION SICKNESS⁵

TIME AFTER EXPOSURE	SURVIVAL PROBABLE (250 r to 100 r)	SURVIVAL POSSIBLE (550 r to 300 r)	SURVIVAL IMPROBABLE (700 or more)
1st week	Possibly nausea, vomiting, and diarrhea on first day.	Nausea, vomiting, and diarrhea in first few hours.	Nausea, vomiting, and diarrhea in first few hours.
2nd week	No definite symptoms (latent period).	No definite symptoms (latent period).	No definite symptoms in some cases (latent period).
3rd week	Epilation Loss of appetite and malaise Sore throat Hemorrhage Purpura Petechiae Pallor Diarrhea Moderate emaciation.	Epilation Loss of appetite and general malaise Fever Hemorrhage Purpura Petechiae Nosebleeds Pallor Inflammation of mouth and throat Diarrhea Emaciation.	Diarrhea Hemorrhage Purpura Inflammation of mouth and throat Fever Rapid emaciation Death (mortality probably 100 per cent).
4th week	Recovery likely in about 3 months unless complicated by poor previous health or superimposed injuries or infections.	Death in most serious cases. (Mortality 50 per cent for 450 roentgens.)	

⁵ Ibid., p. 477.

TABLE 4

SUMMARY OF 11 CASES OF ACCIDENTAL ACUTE WHOLE-BODY RADIATION^{6,7}

DOSE (REM*)	SYMPTOM	TIME TO ONSET OF SYMPTOM
6,000 - 18,000	Shock, Loss of Consciousness Death	1/4 Hour 36 Hours
600 - 1,000	Nausea and Vomiting	1 Hour
365	Nausea and Vomiting	2 Hours
327	Nausea and Vomiting	2 Hours
270	Nausea and Vomiting	4 Hours
236	Nausea	2 Hours
69	None	

* Roentgen Equivalent Mammal

⁶Jammet, H., et al, "Study of Six Cases of Accidental Acute Whole-Body Irradiation," *Revue Francaise d'Etudes Cliniques et Biologiques*, IV, 210-225 (1959).

⁷Hempelmann, L.H., Lisco, H., and Hoffman, J.G., "The Acute Radiation Syndrome: A Study of Nine Cases and a Review of the Problem," *Ann. Int. Rad.*, 36, 279 (1952).

CHAPTER 3

REPAIR VEHICLES SYSTEMS

A system of vehicles, to be feasible for operation within a fallout environment, must provide the necessary degree of radiation protection to keep the repair personnel from receiving harmful doses of radiation while they perform various repair tasks. In Chapter 2 of this report we presented the estimates of the intensity of the fallout threat and the likely damage that might be repaired quickly. In this chapter we shall discuss the types of vehicles that have been considered for the repair objectives.

Any system of repair vehicles for use with land-line communications networks must perform two basic tasks:

1. Transport crews and equipment to and from the repair point or points
2. Provide support to the repair crew while repair is in progress.

PROPOSED SCHEMES OF OPERATION

Because the need for sheltering and the ease with which it can be obtained differ for the two tasks mentioned above, it is helpful to consider the two tasks somewhat independently. Thus we may consider the pay-off for providing a shelter that protects personnel in transit and another that protects personnel engaged in actual repair activity. To combine the two tasks in a meaningful way, a plan or scheme of operation is needed. There are many schemes of operation that might be used for the repair of vital circuit damage. A representative group of these schemes is discussed in the following paragraphs.

Repairs to microwave links differ from repairs to the more usual types of land lines in terms of the number of personnel involved, the skills involved, and the types of equipment required. Consequently, a discussion of the microwave repair problem is presented separately at the end of this chapter.

SCHEME I - SHELTER IN TRANSIT

The first operational scheme considered consists of the normal repair operations carried out under peacetime conditions, but with the use of a specially built

vehicle. Under normal conditions, repair vehicles are dispatched to the repair points by radio. Current American Telephone and Telegraph (A. T. & T.)¹ operations rely most heavily on one- or two-man repair and construction teams for work on aerial wires and cables. A cable-splicing crew, for example, consists of one or two men and a small truck² that has an aerial ladder with a platform on its top to support the man while he splices wires at cable height. The same truck and crew is used also when splices are being made on buried cables or on cables in man-holes. An aerial cable-stringing crew consists of two men, one who rides in a controllable boom-supported bucket² and works at cable height, and one who drives the truck and performs the ground tasks. The vehicle is equipped so that the two-man crew can perform all the tasks required for permanently fastening lengths of cable on poles accessible³ to the vehicle. Even pole setting, a task that was performed previously by crews of five or more men, is now performed by a crew of two men and a special vehicle having a highly mobile, powered auger and a boom for pole handling. The placing of poles, however, appears to be a task that would not be performed at all when the speed of vital communications restoration is of importance. When faced with the need to restore communications quickly, current A. T. & T. procedures are to string a temporary jumper wire on the ground and splice it into service. Later, the more permanent aerial cable is repaired and put back into service.

A scheme of operation patterned after current procedures, but adapted to a fallout environment, would be based on vehicles comparable to these two-man vehicles currently in use. The vehicles would support two-man teams and would be designed to provide a large shelter factor to the crew in transit. During cable laying or splicing operations, the use of current types of vehicles and procedures would virtually eliminate the possibility of providing a large shelter factor for the working personnel. One man of the two-man crew would control the vehicle from within the sheltered driver's compartment and would act as a safety stand-by.

¹Based on interviews with representatives of the New England Telephone and Telegraph Company and of A. T. & T.'s New York office.

²See Appendix B.

³The vehicle must be able to get within ten feet of the poles.

The other man would perform splicing or cable stringing work and be relatively unprotected by the vehicle. The difference in the effective dose rates of the two positions could be reduced by having the two crew members exchange positions after a specified dose had been absorbed by the less sheltered worker. It is obvious that in such a scheme individual dose meters and dose rate meters are a necessity for the intelligent application of available repair manpower.

A dispatching procedure to provide over-all vehicle system control is also essential. Civil Defense damage and fallout data, or other data indicating general predictions of dose rate contour movements, must be utilized at central dispatching offices. Circuit data and possibly detailed network reconnaissance information must also be made available to the dispatcher so that he can make estimates of the places where vital communications repair might be performed safely. Once the approximate locations of possible repairs have been determined, vehicles would be dispatched from the garage. The crews would monitor their instruments during the repair mission and would allow a sufficient margin to return safely to the shelter of the central garage. In areas of light fallout, a crew might perform task after task as instructed by radio dispatch, but would have to maintain a current estimate of the dose that would be encountered during the return to the garage, with a margin of safety to account for unforeseen radiation intensity changes. Even in this case, the crew must be capable of determining when it must stop work and return to the safety of the garage, in order to assure survival.

An artist's conception of this two-man shelter-in-transit vehicle is presented in Figure 2. It should be noted that the vehicle is equipped with tracks to allow it to climb through rubble and over small obstacles. A flexibly mounted periscope provides visibility for driving and for communications line inspection. Figure 2 and the other artist's conceptions that follow represent only initial vehicle concepts and should not be construed to represent the final judgments of Tech/Ops as to the best configuration of a repair vehicle.

SCHEME II - TEAM CONCEPT WITH SHELTER IN TRANSIT

The second operational scheme to be considered is more closely tailored to the requirements of a fallout environment. Because of the limitations imposed by the

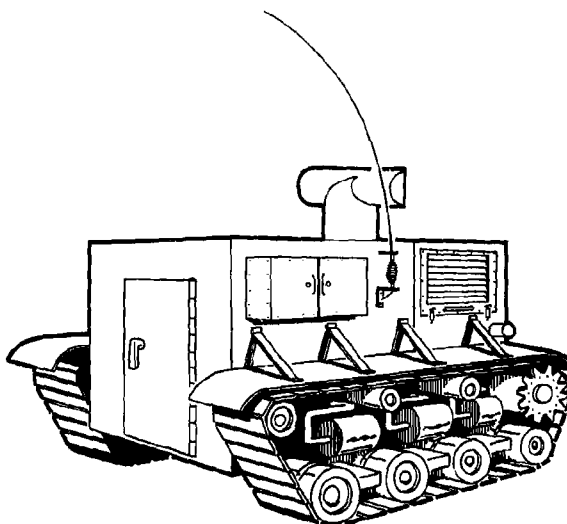


Figure 2. The Two-Man Transit Shelter Vehicle

radiation dose that would be received by the personnel making repairs in unsheltered places, consideration was given to operating schemes that could extend the time of usefulness of a vehicle. A team concept was proposed for this purpose. In this scheme, a heavily sheltered vehicle would carry a team to a repair point, and then the team would accomplish the repair by having one or two members work in the relatively poor shelter of a repair point until they receive some predetermined amount of radiation dose. At this time, they would return to the shelter of the vehicle and be replaced on the repair task by other members of the team. When all team members have been exposed to the precalculated dose, or when the repair has been accomplished, the sheltered vehicle would return to its heavily sheltered garage.

The vehicles required for this scheme of operation differ in one important respect from the vehicles previously discussed. They must, in this case, have a heavily sheltered crew compartment that is larger (capable of sheltering more people) than the crew compartments of the previously described vehicles. This type of vehicle would allow a greater amount of vehicle time to be spent at a single important repair site and, therefore, would allow more lengthy repairs to be

accomplished than the previously discussed vehicle. However, this type of vehicle is wasteful of repair manpower, since only a part of the whole crew can work⁴ at one time.

Figure 3 is an artist's conception of this vehicle while it stands by at a buried cable repair point.

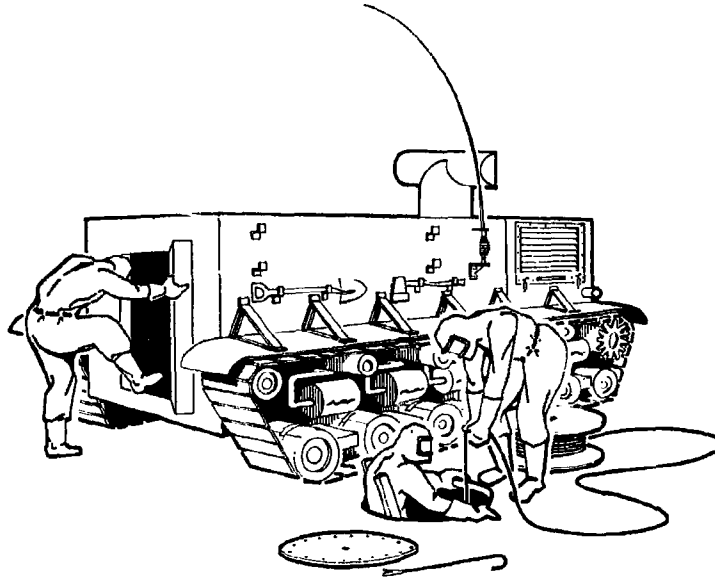


Figure 3. The Four- or Five-Man Transit Shelter Vehicle

SCHEME III - THE WORK CAPSULE

The third operational scheme to be considered is one that provides shelter while repairs are being performed. This scheme, through necessity, involves a vehicle of a somewhat different type than the others previously discussed. The vehicle must be capable of allowing the repairs to be made within a protected capsule. In addition to a sheltered driver's compartment, a sheltered work compartment (or extension of the driver's compartment) must be provided within an

⁴It is not feasible to have more than about two men working at the same splice point, because in larger numbers the workers would get in each other's way.

opening through which cables and wire ends can be led into and out of the work compartment. The tools, equipment, and supplies required for repair operations must be available to the repair crew within the work compartment.

The impact of these requirements on the design of the shelter for this vehicle is that the sheltering efficiency for the vehicle will not be so high as it might be otherwise. In other words, for a given gross vehicle weight limitation, a vehicle of this type would not have so large a shelter factor as could be attained in a vehicle of either of the types discussed previously. For the repair of aerial cables and open wire damage, this type of vehicle has important advantages. The operating scheme appropriate for this vehicle is very simple, since all crew members are equally sheltered. Work that is required outside the vehicle (securing cable ends, clearing obstacles, etc.) should be shared by all crew members to equalize their absorbed doses. Additional vehicle modifications, which would allow the remote manipulation of damaged cable segments, could eliminate much if not all of the need for outside crew activity. For instance, if a controllable boom or telescoping hydraulic arm were attached to the vehicle and fitted with manipulators, cable shears, and an in-haul device, many cable or wire repairs could be performed from within the work compartment. First, the arm would be extended to cut loose a sufficient length of cable from its supporting poles, and then the loose cable end would be hauled toward the vehicle and in through an opening in the floor or side of the work compartment. The loose end of a jumper cable or wire would be attached to the appropriate wires from the damaged cable, and the spliced joint would then be pushed back outside of the work compartment onto the ground. In most cases, jumper cables could be laid directly on the ground. When necessary, however, suitable fixtures could be added to the manipulator boom to allow the jumper to be hung onto available poles or other available structures. Next, this vehicle (or a second one) would string the jumper cable to the point where its other end is to be connected to bridge a gap, and the preceding operation would be repeated. Splicing, in this case, might also involve circuit testing (when circuit continuity is re-established), and therefore some testing equipment should be provided within the work compartment.

Temporary repairs to buried cables or cables in conduit would require a different sort of operating procedure. For the quickest communications restoration, jumper

cables would have to be run between the manholes or terminals on either side of the damage. A man would be required to enter the manhole and attach the end of a jumper cable to the appropriate terminals. The radiation protection afforded by the manhole itself would be of great advantage. If an arrangement were made in the design of the vehicle to allow the vehicle to be driven over the manhole to act as a "skyshine" barrier, manhole shelter factors in excess of 100 could be expected. Even better shelter factors could be achieved if a closer fit between the vehicle floor and the manhole top were arranged.

The operation of this vehicle is the same as the operation of the other vehicles with respect to vehicle dispatching, the monitoring of individual dosimeters and dose rate meters, and the making of the decision to return to a sheltered garage.

Figure 4 shows the two-man transit and repair shelter in the process of retrieving the end of a broken cable.

Figure 5 illustrates the same vehicle in the process of aiding in the erecting of a temporary microwave tower. In this case, the shelter is shown mounted on an earth mover chassis instead of on tracks.

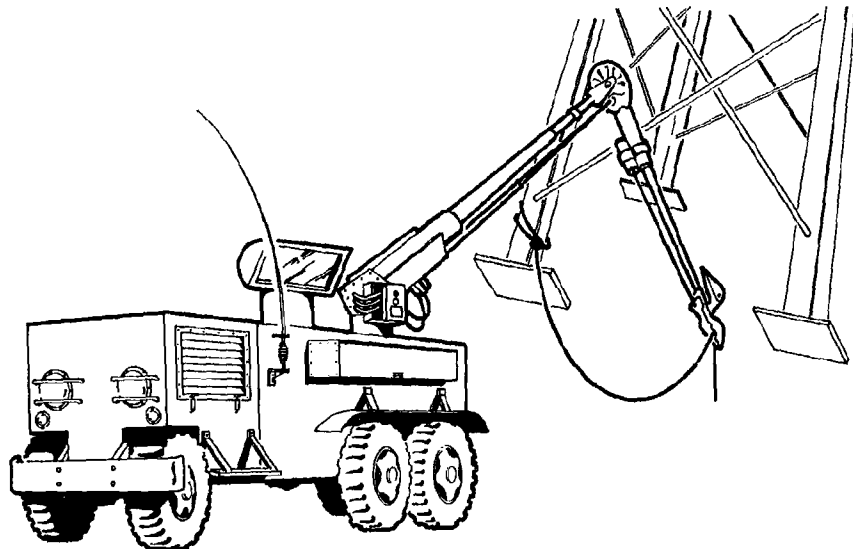


Figure 4. The Two-Man Transit and Repair Vehicle at a Microwave Repair Point

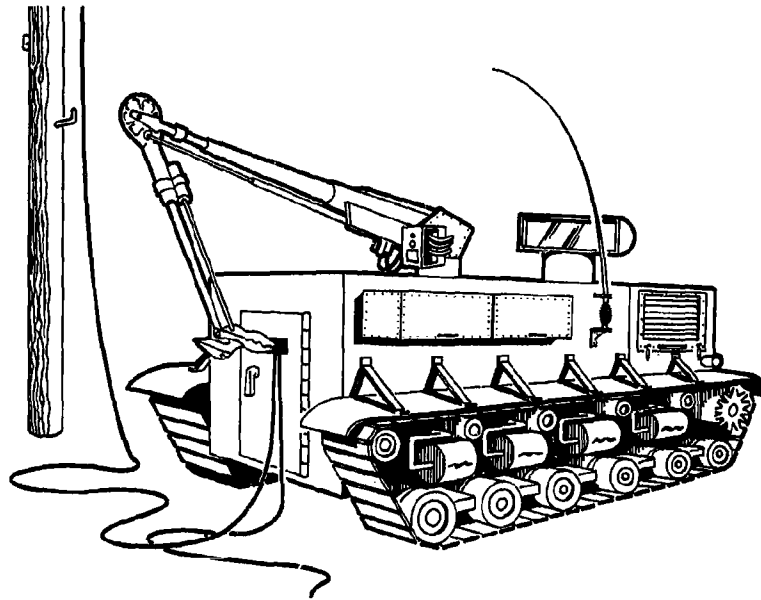


Figure 5. The Two-Man Transit and Repair Vehicle

SCHEME IV - AIRBORNE ASSISTANCE

An additional scheme that might be used in conjunction with the schemes described previously is one that involves the use of helicopter air transportation for the repair vehicle, the required supplies, and the personnel. Considerable advantage may be obtained from this use of air transportation, provided that the gross vehicle weight does not exceed the safe lifting capacity of a helicopter (such as the Sikorsky Flying Crane). Helicopter travel time is considerably less than the travel time for ground-supported vehicles, but when fallout is on the ground, the dose rate along the helicopter travel path is considerably lower than that which would be encountered by a vehicle on the ground. (It is estimated⁵ that an aircraft flying five thousand feet above contaminated ground surface has an effective shelter factor of 100,000, by virtue of its vertical distance from the field.) Even if fallout were still falling through the atmosphere, the helicopter could evade intense radiation areas more easily and more quickly than ground-supported vehicles. Also,

⁵U. S. Government Printing Office, "The Effects of Nuclear Weapons" (Washington, D. C. : 1957) p. 437.

ground obstacles and congestion that might seriously hamper ground vehicle movements would not be a problem to a helicopter.

Because of the gross vehicle weight limitations imposed by the lifting capacity of the helicopter, the shelter factor attainable in air transportable vehicles is severely limited. The exposure times for airborne vehicles would be on the order of half that which could be obtained by a ground-supported vehicle. However, a larger part of the exposure time would be spent at the repair point.

After landing the vehicle near its point of repair, the helicopter would maintain radio contact with it (perhaps one helicopter could maintain contact with a group of vehicles) for the purposes of bringing in the necessary supplies and of retrieving the vehicle after repairs are completed, or in the case of an emergency. The light shelter afforded by the helicopter cockpit would force the helicopter to spend a minimum amount of time on the ground in the radiation field near the repair vehicle. Either it would have to land at some nearby uncontaminated point, or it would have to return to the sheltered garage or source of supply.

A helicopter could also be of advantage in the reconnaissance phase of the repair operation, because its speed and effective shelter factor would facilitate the development of good estimates of the feasibility of repairing individual communications routes.

MICROWAVE LINKS

Damage to microwave transmission towers presents a repair problem of a type very different from those previously discussed. In the first place, the towers often are not easily accessible to ordinary repair vehicles because of the surrounding terrain. Tower construction is an engineering effort of considerable magnitude. Many towers are designed specifically to fit relay needs at a single point in order to allow line-of-sight transmission to other towers or terminal points. Heavy construction equipment is usually required by tower erectors, and considerable time is involved in the construction of permanent towers. An attempt to solve this kind of building and installation problem has been made by A.T. & T. by prefabricating a small, transportable building and tower. These standard buildings

and towers may prove highly useful where portability is an important factor, such as in replacing a complete microwave repeater station.⁶

In summary, it appears that any damage to a microwave tower that results in its collapse or severe misalignment must be classified as major damage and therefore be excluded from detailed consideration in this study. In cases of minor misalignments and electronics repair and maintenance, it is extremely difficult to shield workers from radiation. If the worker must climb to the top of the tower, it is unlikely that he can be shielded at all. Vertical distance attenuation cannot be expected to be sufficient at tower height to be of great consequence.⁷ Workers who must service the equipment that is housed in the building near the tower also cannot be shielded without great difficulty. The building itself does not provide good shelter, and a portable temporary shelter either for the repair man or for the building as a whole seems infeasible. Often it may not be practical to take the item needing repair work to the shelter of the vehicle. The most encouraging thought is the fact that minor repairs to microwave equipment can be expected to be accomplished in a relatively short time if there is both coordination and communication with the other personnel at connecting towers. The vehicle required for these repairs must provide shelter in transit and must carry sufficient supplies and equipment, but beyond this it can have no special features that would provide on-the-job protection. A shelter-in-transit vehicle seems to be all that can be provided.

A helicopter could be used to great advantage when repairs must be made to chains of microwave towers. Rough estimates could be made from a helicopter of the degree of damage to a microwave tower to supplement data generated at manned stations. If the damage appeared to be slight, the helicopter might bring in a work party for a short period. If the damage to a tower were severe, temporary towers and equipment, if available, might be carried to the appropriate places and dropped into place by a crane-type helicopter. Without the advance preparation of materials

⁶J. W. Halliday, "Packaged Buildings for TJ Microwave Systems," Bell Laboratories Record (October 1960) p. 381.

⁷U.S. Government Printing Office, "The Effects of Nuclear Weapons" (Washington, D. C.: 1957) p. 437.

and sites, however, the repairs to severely damaged microwave towers are likely to require larger amounts of time, and this involves considerable delay before circuit restoration can be completed.

PROPOSED VEHICLE CONFIGURATIONS

For the purpose of making calculations relating to capsule shelter (attenuation) factors and capsule weights, three capsule shapes were determined. The shapes (Figures 6, 7 and 8) define the inside volumes estimated to be necessary for the three vehicle types discussed previously. Any material used to shelter these volumes must be placed around the outside of the shapes.

TWO-MAN VEHICLE - TRANSIT SHELTER ONLY

The two-man vehicle with transit shelter is designed to provide a high protection factor for repair personnel while in transit to the repair site. No shielding protection is provided within the cab for repair equipment and materials, since adequate protection from contamination could be afforded by having these items protected by impermeable covers, such as plastic bags. Since no repairs are to be made within the confines of the vehicle and the transit time is not expected to be much greater than one hour, the cab of the vehicle has been designed to maximize protection rather than to provide comfort. The cab dimensions are roughly equivalent to those of a small sports car, with the occupants sitting approximately six inches above the floor. Figure 6 illustrates the proposed cab dimensions (inside) for this type of vehicle.

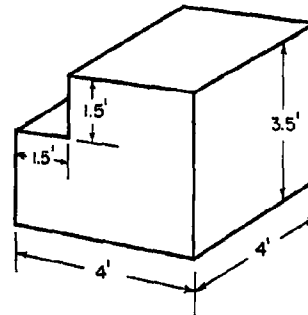


Figure 6. Cab Dimensions for Two-Man Vehicle - Transit Shelter Only

FOUR- OR FIVE-MAN VEHICLE - TRANSIT SHELTER ONLY

This vehicle provides adequate space and protection for four or five men to allow for interchange of repair personnel engaged in repairs that would involve

prohibitive radiation exposure for a single team. The vehicle provides no protection for equipment or materials and was designed for transit times of approximately one hour in duration. The cab is essentially the same design as the previous vehicle with the addition of a seating compartment capable of sheltering two or three passengers. Figure 7 illustrates the proposed cab dimensions (inside) for this type of vehicle.

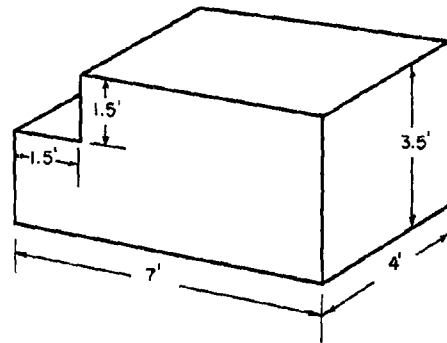


Figure 7. Cab Dimensions for Four- or Five-Man Vehicle — Transit Shelter Only

TWO-MAN VEHICLE - TRANSIT AND REPAIR SHELTER

This vehicle provides maximum repair flexibility for a two-man repair crew. The dimensions of the cab and working compartment have been chosen to provide adequate space for materials and equipment and still leave sufficient room to perform repair tasks within the confines of the vehicle. The vehicle is smaller in terms of storage volume for equipment and materials than similar trucks presently used by A. T. & T. , but it is felt that judicious selection of equipment and tight packing would provide up to a 50% reduction in storage volume. Figure 8 illustrates the proposed dimensions for this type of vehicle.

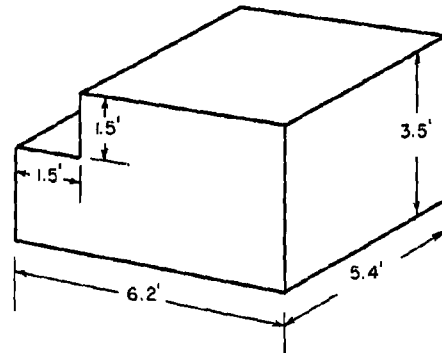


Figure 8. Dimensions for Two-Man Vehicle — Transit and Repair Shelter

SHIELDING CALCULATIONS⁸

Radioactive fallout emits three types of radiation: (1) alpha rays, (2) beta rays, and (3) gamma rays. Alpha rays, because of their greater mass and charge, cannot penetrate clothing and probably cannot get through an unbroken layer of skin. Beta rays are more penetrating, but complete protection may be afforded by a layer of average weight clothing. Gamma rays, being physically identical with high-energy X-rays, are extremely penetrating and are impossible to absorb completely. In this report we shall be concerned with the shielding from gamma radiation, because adequate attenuation of gamma rays will also provide more than adequate protection from alpha and beta radiation.

Gamma ray photons travel in straight lines until they collide or interact with atoms, at which time the photon is either absorbed or ricochets and continues traveling in a new direction with a lower energy. The former interactions are called absorptive interactions; the latter are called scattering interactions. The average distance between interactions in air is several hundred feet, which is much larger than the dimensions of feasible vehicles. Most gamma ray interactions within vehicles, therefore, will not take place in air, but in the roof, walls, and floor of the vehicle, where the average distance between interactions is much smaller.

Detailed sheltering calculations take into account the following factors in the determination of a shelter (attenuation) factor:

1. The location of the radiation field relative to the shelter
2. The shape of the shield
3. The mass thickness of the shield (weight per unit area)
4. The type of the sheltering substance.

The following assumptions are adopted for all shielding calculations: (1) fallout is assumed to be distributed uniformly over the exposed surfaces according to their horizontal projections, and (2) fallout on vertical surfaces is not considered significant. Materials with high atomic numbers, such as lead, make the best shielding

⁸L. V. Spencer, "Structure Shielding Against Fallout Radiation" (unpublished manuscript) U. S. Bureau of Standards (Washington, D. C.).

agents, since they absorb as well as scatter radiation. At this time, no detailed data are available on the shielding effectiveness of lead as compared to ordinary construction materials, and, therefore, our calculations were made using steel as the shielding agent. Steel appears to be the most practical material for vehicle construction. Lead is more efficient against radiation on a per pound basis, but it is considerably more expensive. Concrete and other construction materials are too bulky or otherwise not suitable for a moving vehicle.

In order to reduce the complexity of the calculations and to remain within the present state of the shielding art, all vehicle shapes have been treated as unbroken surfaces possessing no indentations or irregularities. The floor of the vehicle was assumed to be elevated three feet above the ground, and the detector response was calculated for a point in the center of the floor 1-1/2 feet above its surface. A height of 1-1/2 feet was chosen to approximate the position of the vital organs of personnel seated within the vehicle.

Shielding calculations were carried out in the manner prescribed by Spencer in his unpublished manuscript.⁹ In these calculations, the total radiation contribution was broken down as follows:

1. Roof contribution
2. Ground contribution
 - a. Direct
 - b. Scattered
 - c. Skyshine
3. Floor contribution

Table 5 presents the results of the shielding calculations, which illustrate the relationship between protection factors and gross vehicle weights for the three proposed vehicle configurations.

Because of the load limits of bridges and roads (and in peacetime because of legal load limits), the upper limit on gross vehicle weight has been established at

⁹Op. cit.

TABLE 5
RELATIONSHIP BETWEEN PROTECTION FACTOR AND VEHICLE WEIGHT

VEHICLE	SHIELDING MATERIAL	GROSS WEIGHT (LBS)	PROTECTION FACTOR
Type I	1 in. steel plate	4,100	2.5
	3 in. steel plate	11,700	13
	7 in. steel plate	30,500	390
Type II	1 in. steel plate	6,100	2
	3 in. steel plate	19,000	13
	7 in. steel plate	46,200	395
Type III	1 in. steel plate	6,100	2
	3 in. steel plate	19,600	13
	7 in. steel plate	51,700	395

30 tons.¹⁰ For a proposed vehicle to be considered feasible, it must provide the required protection factor while maintaining a gross weight of less than 30 tons.

Table 5 indicates that vehicles covered with approximately 7 inches of steel can provide sizable protection factors and do not exceed the weight limit. In all cases, a sufficient weight margin has been allowed for the chassis, running gear, and equipment weights. Lighter weight shielding does not provide adequate protection for the repair systems proposed in this report.

It is possible to increase the protection factor for the three types of vehicles by the simple expedient of removing the fallout from the roof of the vehicle. This could be accomplished by installing a disposable tarpaulin to cover the roof. Effective roof decontamination procedures would allow the redistribution of shielding from the roof to the sides and floor, thereby increasing the protection factor while simultaneously removing the roof contribution of approximately 11% of the total radiation contribution.

¹⁰ E. Callahan, F. Brooks, et al., "Operations Analysis of a Truck Mounted Missile System" (Secret) Technical Operations, Inc., Report No. TO-B 60-35 (15 August 1960).

CHAPTER 4

OPERATIONAL EFFECTIVENESS OF THE REPAIR VEHICLE SYSTEMS

The purpose of a repair vehicle is to aid in the rapid restoration of communication facilities, while maintaining a specified level of radiation protection for repair personnel. To accomplish this objective, the repair vehicle designer must know: (1) the type of environment within which the vehicle is to operate, (2) the methods at his disposal for attenuating the effects of the environment on both vehicle and personnel, and (3) the distribution of probable repair tasks with respect to duration and manpower requirements. A careful evaluation of these factors indicates that the ideal repair vehicle system should possess the following characteristics:

1. Short reaction time¹—the vehicle should have the ability to enter the damage area shortly after the attack occurs.
2. High repair flexibility—the vehicle should be capable of being utilized successfully by the repair personnel for a wide spectrum of probable repair tasks.

In this study, various feasible repair vehicles are investigated, and their operational effectiveness is measured by the degree to which they approach the ideal repair vehicle system.

THE POST-ATTACK ENVIRONMENT

Assuming that the communications facilities themselves are not targets of the attack, the areas of immediate interest are: (1) the area of probable damage in the vicinity of a bombarded site, and (2) other areas containing communications facilities that are liable to routine failure. The repair of blast-induced damage is likely to be of much more importance than the repair of routine failures, and, therefore, this study will concentrate on the impact of this first area of damage. It is very likely that vehicle systems that are feasible for the repair of blast damage will be entirely adequate for the repair of routine failures in the fallout environment as well.

¹The reaction time is the time elapsed between the time of the attack and the time at which the vehicle enters the damage area to perform repairs.

The area of probable repairable damage was defined as that area outside the lip of the bomb crater and extending out to the two psi overpressure level (a distance of 10.1 miles for a 7 MT weapon).² This definition was believed to be a realistic interpretation of the repair area because: (1) within the crater itself facilities will be damaged beyond repair, (2) the weakest element in the communication system is the telegraph pole with aerial cable, which may be expected to fail at two psi overpressure, and (3) at two psi overpressure, fragments from buildings, trees, etc., may cause damage to aerial cables. A peak overpressure of two psi corresponds approximately to a peak particle velocity of 70 mph.

RADIATION LEVELS WITHIN THE REPAIR AREA

It can be shown to be reasonable that targeted sites may be subjected to bombardment from as many as twenty weapons, depending upon the importance and hardness of the site. In the absence of experimental data on multiple weapon detonations, we assume that the fallout effects from multiple weapons are additive. Figure 9 illustrates the radiation levels that might exist within the repair area at various times after the surface burst of a 7 MT weapon. Figure 10 illustrates the radiation levels at one hour after burst from a multiple weapon bombardment. Figures 9 and 10 were developed through the use of the fallout model discussed in Chapter 2.

It is apparent that during the period from the initial burst to one hour after attack the radiation levels will be so intense as to preclude unshielded open-air repair activities of any practical duration. The dose rates at the end of the first hour for over 50% of the repair area will range from more than 135 roentgens/hr for the single weapon case to more than 2,000 roentgens/hr for the extreme case of 20 weapons. Figure 11 shows, for various numbers of weapons, the per cent of the repair area having a dose rate greater than 250 roentgens/hr at one hour after burst.

After 12 hours, the radiation levels from the single weapon case will diminish to the point where unshielded repair activity can be carried out for at least 10 hours without exceeding the specified accumulated dose of 250 roentgens.

²U. S. Government Printing Office, "The Effects of Nuclear Weapons" (Washington, D. C.: June 1957.)

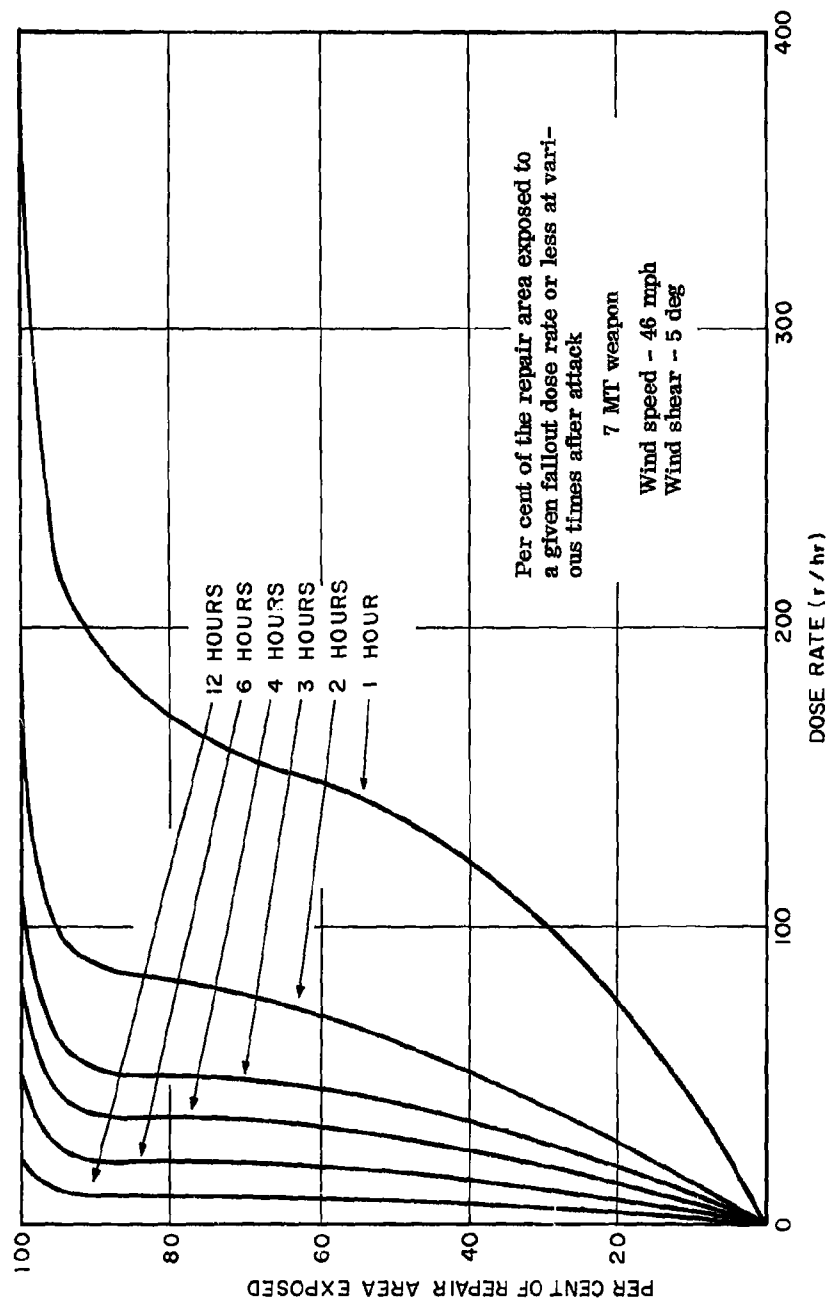


Figure 9. Repair Area Radiation — One Weapon

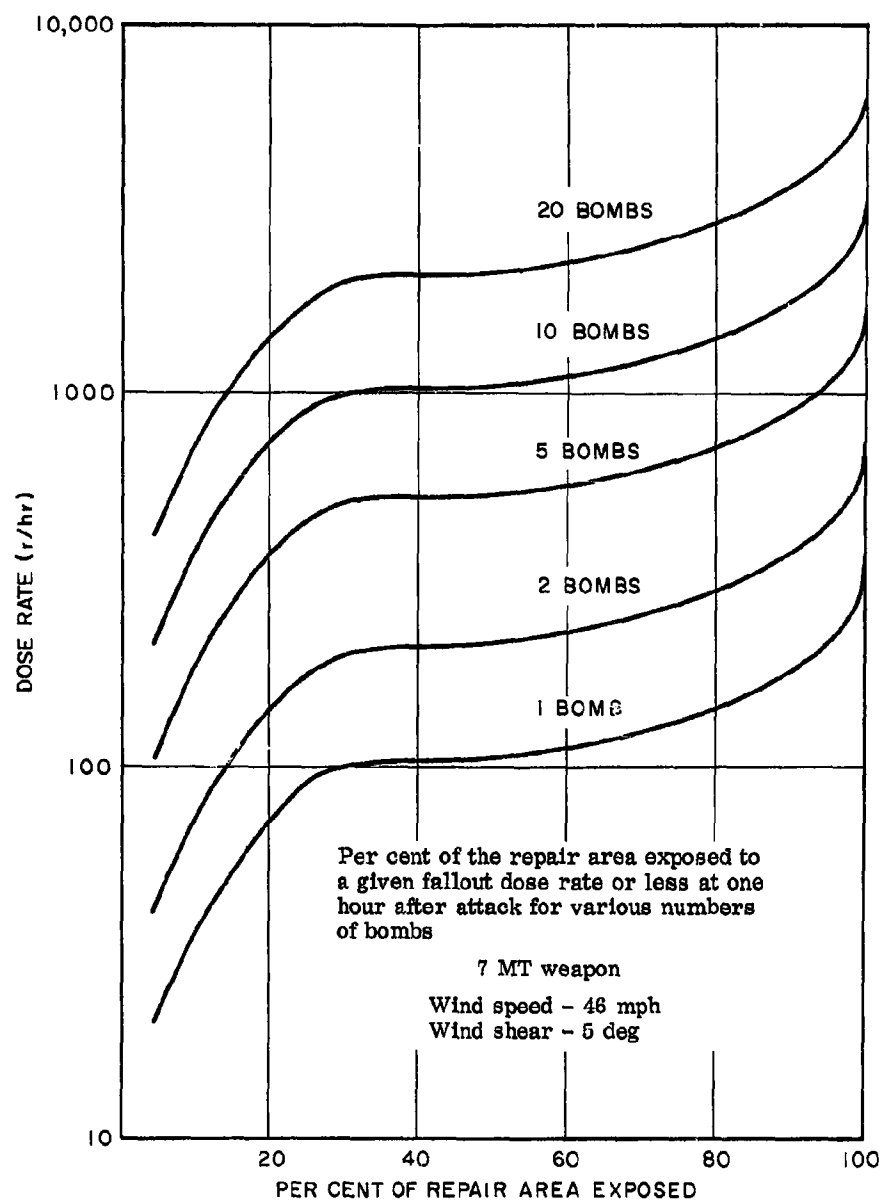


Figure 10. Repair Area Radiation — Multiple Weapons

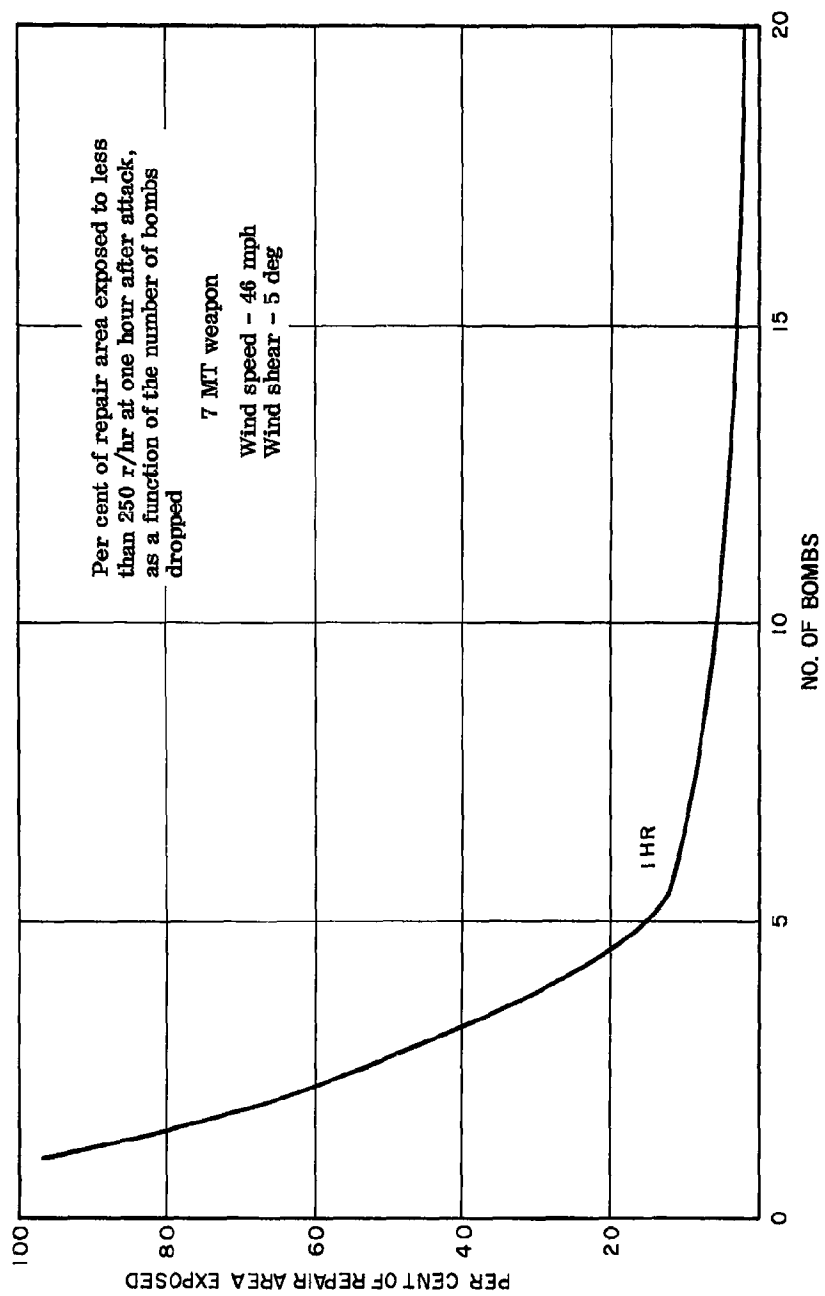


Figure 11. Repair Area Exposure

RADIATION LEVELS WITHIN THE TRANSIT AREA

The transit area is that region through which the repair vehicle must pass to get from the sheltered garage, located at a safe distance from potential targets, to the repair site. The transit area hypothesized in this study extends for a distance of approximately 20 miles away from the outer boundary of the repair area. These boundaries have been chosen arbitrarily to minimize the danger of blast and radiation damage to the garage, while still keeping it within feasible driving range of probable repair sites.

Travel time for the repair vehicle could be reduced by locating a blast-hardened and fallout-protected garage in the repair area. However, it is clear that the stated definition of the transit area does tend to exaggerate the radiation protection problem. Any vehicle system using this definition for the transit area will be even more feasible if the required amount of vehicle travel is reduced. Figure 12 illustrates the radiation levels that might exist at various times after the surface burst of a 7 MT weapon. Figure 13 illustrates the radiation levels from a multiple weapon bombardment at one hour after burst.

REACTION TIME AND ATTENUATION REQUIREMENTS

The ability of the repair vehicle to enter the damage area soon after the attack occurs will be primarily affected by the radiation levels within the damage and transit areas. Although the dose rate decreases with time after all the fallout has come down (approximately $H + 1$ hours for our purposes),³ radiation levels within the damage and transit areas will still be too high for some time after the attack to allow unshielded repair activity of any practical duration. To enable repairmen to operate within the damaged area, the repair vehicle must be capable of restricting the total accumulated dose to personnel to an amount below the specified limit of 250 roentgens. The vehicle attenuation requirement will then be determined by: (1) the existing radiation levels, (2) the time of entry after attack, and (3) the duration of the mission.

The radiation levels from one multiple-weapon bombardment at various times after attack were shown in Figures 9, 10, 11, 12, and 13. These graphs

³H is the time of detonation.

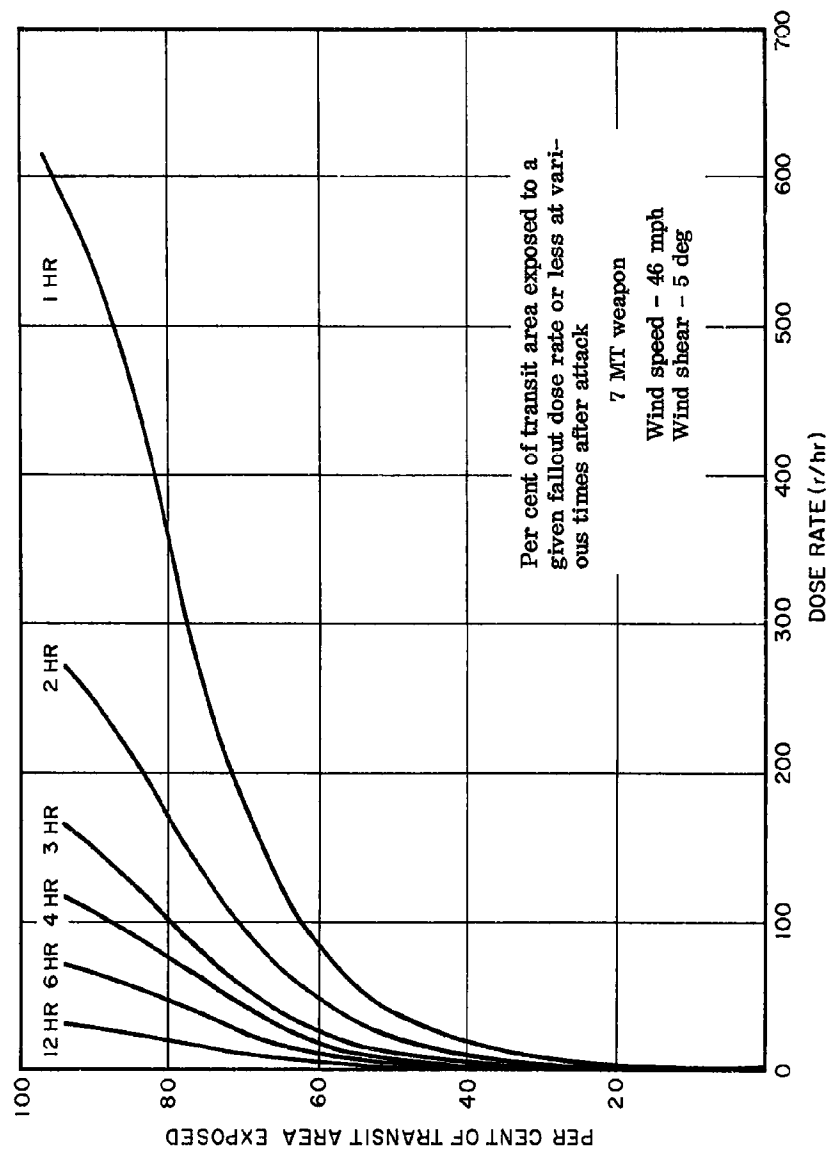


Figure 12. Transit Area Radiation — One Weapon

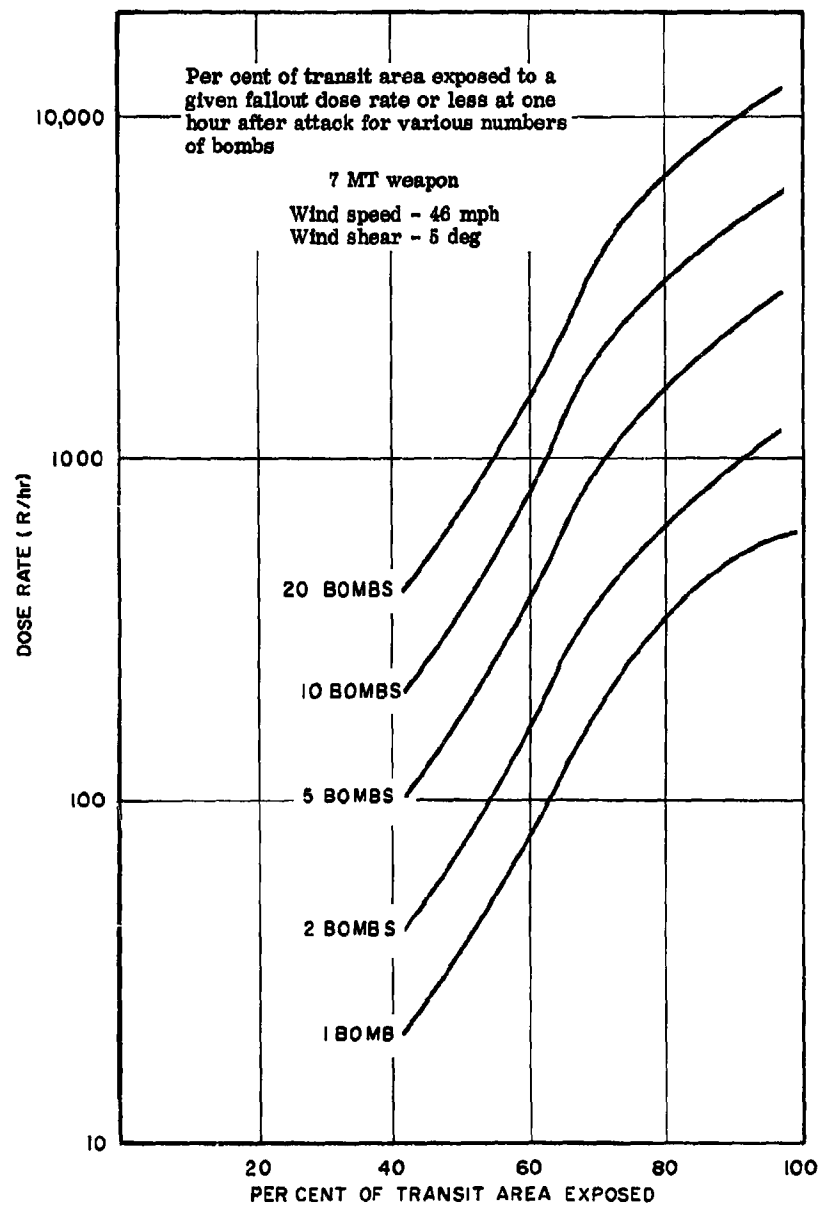


Figure 13. Transit Area Radiation — Multiple Weapons

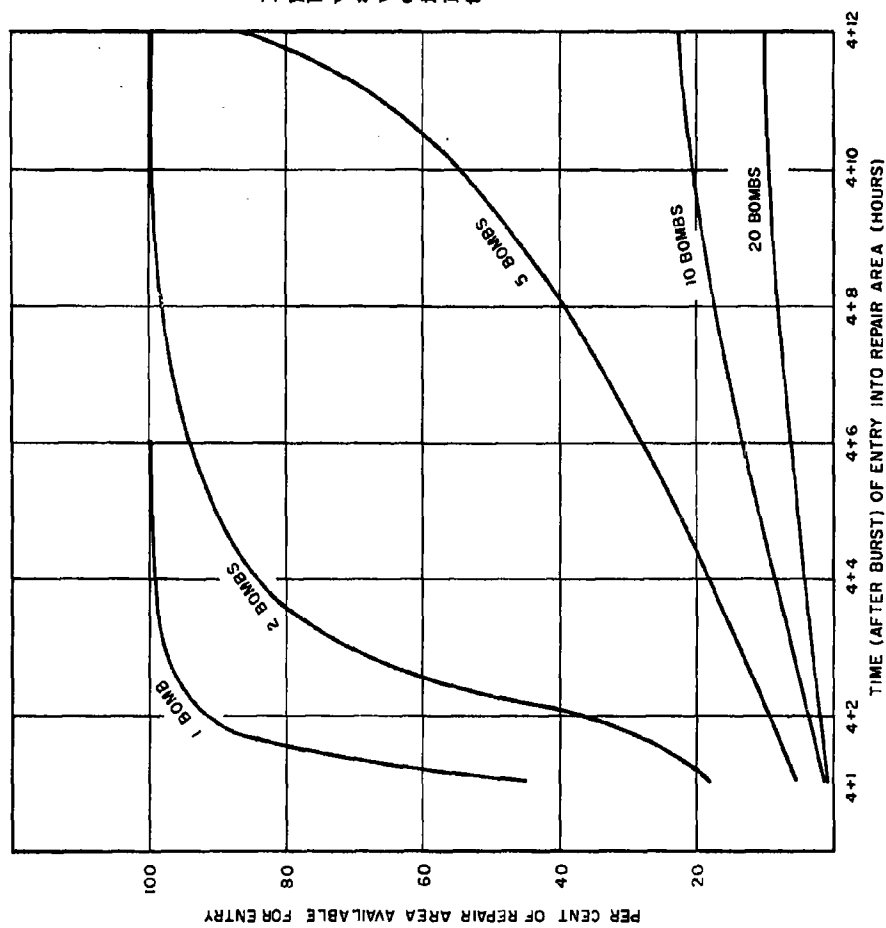
were combined with the radioactivity decay rate approximation ($R_2 = R_1 \Delta t^{-1.2}$) to yield Figures 14, 15, and 16, which illustrate the per cent of the repair area that is available for entry for an eight-hour repair at various times after attack. Curves have been developed for three different shelter factors and for five levels of bombardment. A mission time of eight hours was chosen as being representative of a normal working shift for repair personnel.

Figure 14 indicates that at $H + 1$ hour, less than 50% of the repair area is accessible for unsheltered repair activity of greater than eight hours duration, even if only one bomb is detonated. If entry is delayed until $H + 2$ hours, the accessible portion of the damage area rises to 93%. For the 20-bomb attack, unsheltered entry is prohibited for over 90% of the repair area, even after 12 hours have elapsed. It is apparent that for immediate entry after the attack, the vehicles must be capable of providing shelter factors of approximately 30, if personnel are to operate in the damage area for 8 hours or more.

Thus far we have tacitly assumed that the repair vehicle is capable of completely shielding personnel from radiation during their time in transit to the repair site. This will only hold true, however, if the shelter factor shown to be necessary for the repair area operation is much higher than that required during transit time. Figure 13 illustrates the prevailing radiation levels within the transit area at one hour after attack for various levels of attack. If access is to be made available to at least 90% of the transit area in the 20-bomb attack, a shelter factor at least one order of magnitude greater than that required in the repair area is necessary. Therefore, the vehicle protection factor was determined by the radiation levels existing within the transit area, rather than by the repair area levels. For all proposed vehicle configurations, the 7-inch steel plate design has been found to offer adequate protection after $H + 1$ hour to personnel traversing the transit area.

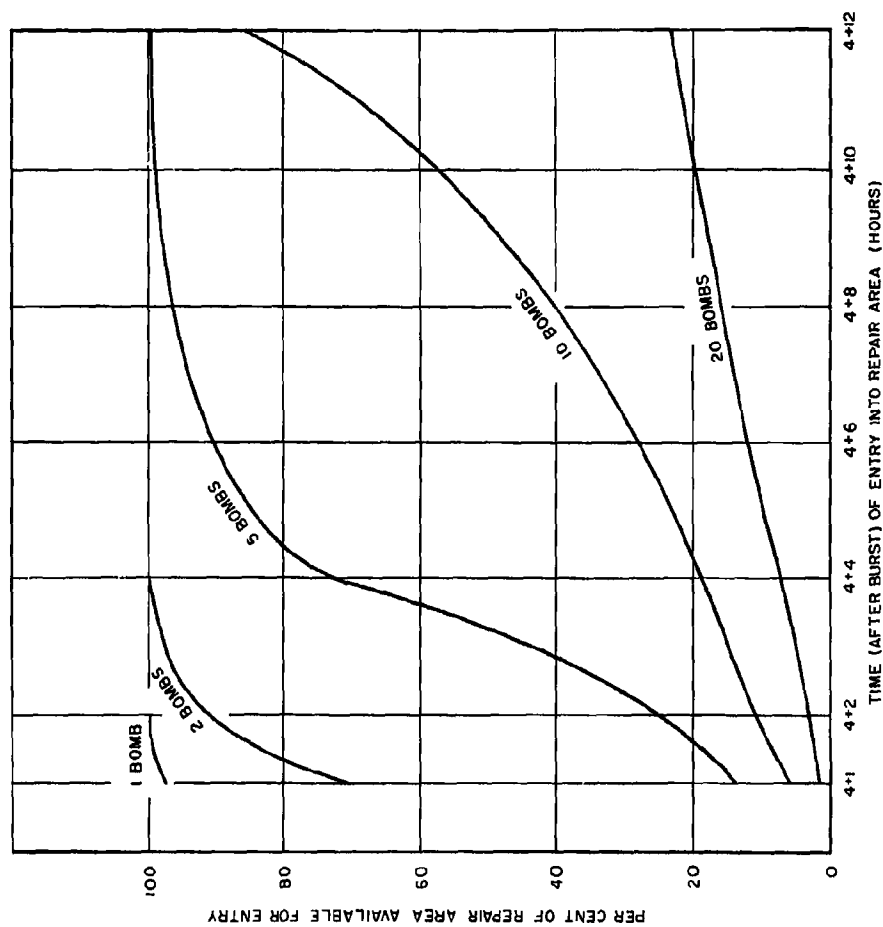
THE DOSE MODEL

The dose model attempts to integrate knowledge of the post-attack environment with factors affecting vehicle performance to enable the repair system designer to measure the operational effectiveness of the proposed repair vehicle systems operating under the total dose constraint.



Per cent of re-
pair area availa-
ble for entry at
various times
after attack for
various numbers
of bombs, keep-
ing total accumu-
lated dose less
than 250 r
Protection fac-
tor = 1
Stay in repair
area = 8 hours

Figure 14. Repair Area Accessibility — Shelter Factor 1.0



Per cent of repair area available for entry at various times after attack for various numbers of bombs, keeping total accumulated dose less than 250 r
Protection factor = 2
Stay in repair area = 8 hours

Figure 15. Repair Area Accessibility — Shelter Factor 2.0

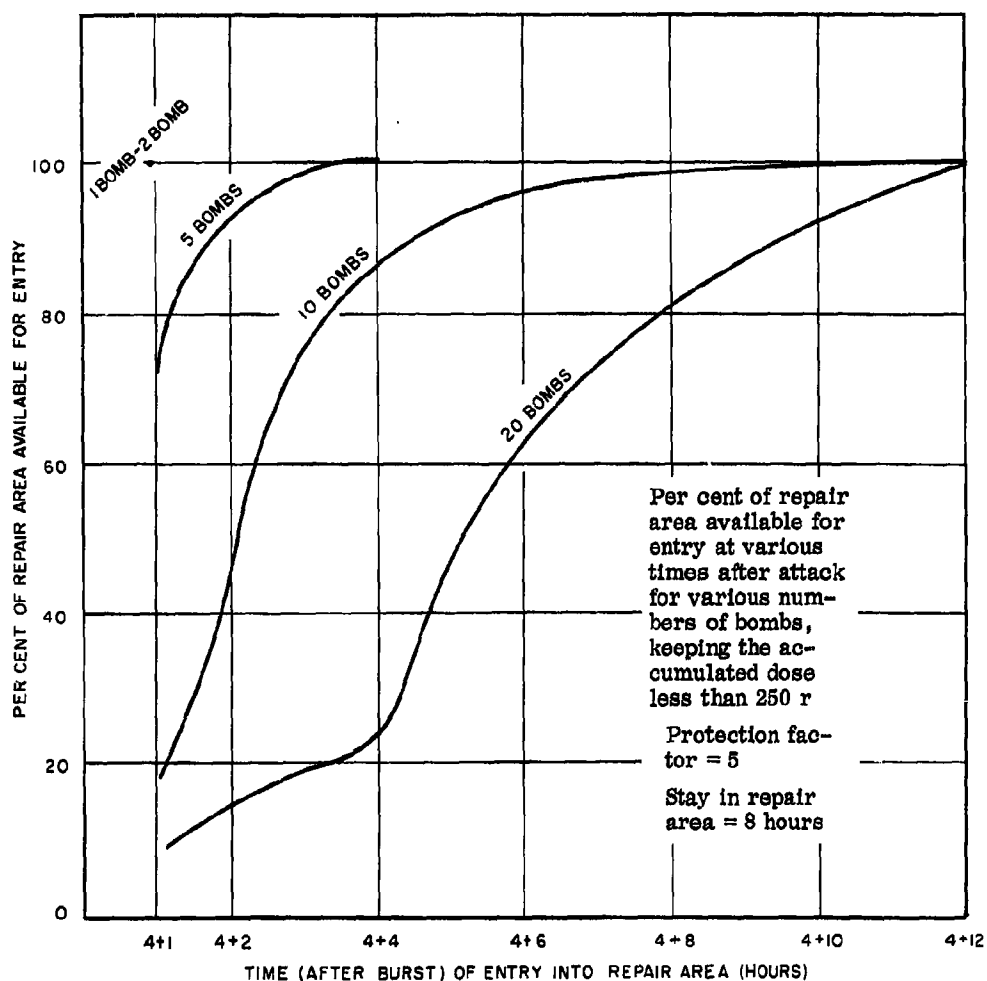


Figure 16. Repair Area Accessibility — Shelter Factor 5.0

DOSE ABSORPTION

The total accumulated dose may be conveniently divided into three components: (1) the dose absorbed in traveling through the transit area, (2) the dose absorbed in traveling through the damage area to the repair site, and (3) the dose absorbed during the actual repair work. Although there is no distinct physical separation between radiation levels existing at the boundary of the repair and the transit areas, road conditions are likely to alter perceptibly in this vicinity due to the presence of debris, tending to decrease the vehicle velocity and increase the exposure time. The dose absorbed during actual repair activity is given separate consideration to facilitate the evaluation of various sheltering schemes that might be used while repairs are being accomplished.

Transit Area Dose Absorption

An accurate estimate of the dose acquired during transit would require knowledge of the following information: (1) the probable routes to be traveled by the repair vehicle, (2) the dose rate existing at each point on the route at the time it was reached, and (3) the time spent in passing from point to point. Even assuming that all fallout has arrived within the repair and the transit areas by $H + 1$ hour, the situation is complicated by the large number of possible routes, the possible variation in local dose rates due to micrometeorological factors, and the lack of knowledge about existing hot spots and about the time required to traverse various regions under post-attack conditions. In the absence of specific information, a reasonable, conservative approximation of existing dose levels may be made from Figures 12 and 13, by choosing the maximum radiation level to which the least affected 90% of the transit area is exposed. This estimate provides a reasonable approximation for planning purposes, because: (1) post-attack reconnaissance or judicious "guesstimates" may allow for avoidance of hot spots that may occupy not more than 10% of the transit area, (2) there will probably be a certain percentage of the transit area inaccessible to travel because of natural obstacles and debris, and (3) in the absence of reconnaissance, this method provides a conservative estimate of the existing radiation levels. Using this method, radiation level estimates may be made for various times after attack and for selected bombardment intensities.

Repair Area Dose Absorption

Estimates of the situation within the repair area suffer from the same lack of information as described previously for the transit area and are further complicated since the location of damaged facilities may require a trial and error approach. Previous calculations revealed that the vehicle protection factor was determined by the radiation levels within the transit area. Since the vehicle protection factors determined previously are sufficient to protect personnel at any point within the repair area, a conservative estimate of existing radiation levels for planning purposes might be the maximum dose rate within the repair area. Calculations of repair area dose absorption based on the maximum dose rate within the repair area would provide an ultraconservative estimate, even though the total area may not be accessible due to debris, etc.

Repair Task Dose Absorption

Once an estimate of the representative radiation level within the repair area for a given time has been made, the only task remaining is to determine the duration of the repair task. The dose accumulated during the actual repair task may be found by a simple multiplication of the two factors.

The Form of the Dose Model

The total accumulated dose may be expressed as the sum of the doses absorbed in traveling through the transit and repair areas respectively, plus the dose absorbed during the actual repair task. A mathematical model was used to produce these dose rates; the symbols used in the model have the following meanings:

- d_o = the distance from the point of the garage to the outer edge of the repair zone (miles)
- d_i = the distance from the outer edge of the repair zone to the repair site (miles)
- \bar{v}_o = the average vehicle velocity within the transit zone (mph)
- \bar{v}_i = the average vehicle velocity within the repair zone (mph)
- s_o = the vehicle protection factor

s_i = the protection factor at the repair site ($s_i = s_o$ for repairs made within the repair vehicle; $s_i = 1$ for unshielded repair work)
 t_r = the time required for the repair task (hours)
 \hat{R}_t = the maximum dose rate to which the least affected 90% of the transit area is exposed at time t
 \hat{R}_t^1 = the maximum dose rate to which the repair area is exposed at time t .

The doses for the transit area, the repair area, and the repair task are computed separately and then added together to give the total absorbed dose, as follows:

$$\text{dose absorbed while traversing the transit area} = \frac{d_o}{V_o} \hat{R}_t$$

$$\text{dose absorbed while traversing the repair area} = \frac{d_i}{V_i} \hat{R}_t^1$$

$$\text{dose absorbed during the repair task} = t_r \hat{R}_t^1$$

$$\text{total absorbed dose} = \frac{d_o}{V_o} \hat{R}_t + \frac{d_i}{V_i} \hat{R}_t^1 + t_r \hat{R}_t^1.$$

The introduction of a protection factor serves to decrease the absorbed dose by a factor equal to the protection factor. Therefore, the equation for the total absorbed dose is as follows:

$$\text{total absorbed dose} = \frac{1}{s_o} \left[\frac{d_o}{V_o} \hat{R}_t + \frac{d_i}{V_i} \hat{R}_t^1 \right] + \frac{1}{s_i} \left[t_r \hat{R}_t^1 \right] \quad (I)$$

Equation (I) provides a method for evaluating alternative repair systems, under the constraint that the total accumulated dose be less than 250 roentgens.

EVALUATION OF ALTERNATIVE SYSTEMS

Initially, repair systems may be separated into two broad categories: (1) those that provide radiation protection during the repair phase as well as during the transit phase, and (2) those that provide protection during the transit phase only.

Repair systems of the second category will have no flexibility, since they provide practically no more protection during the repair task than does ordinary clothing. The reaction time of these systems will be determined primarily by the radiation levels existing within the repair area at the proposed time of entry, assuming that adequate shelter is provided during the transit phase. Repair systems of the first category will have varying degrees of flexibility and reaction time, depending upon their speed of operation, the protection factor, and the configuration.

REPAIR SYSTEMS PROVIDING SHELTER DURING THE TRANSIT PHASE ONLY

The reaction time of these transit shelter systems depends upon the amount of the repair area that is accessible with safety to unsheltered personnel at various times after attack. It makes no difference how rapidly the transit phase is accomplished if personnel cannot begin repair work because the radiation levels are too high. Figure 9 illustrates that at one hour after attack at least 96% of the repair area will be exposed to less than 250 roentgens/hr by a single bomb attack. However, Figure 11 shows that this area decreases exponentially as the number of bombs increases and approaches zero under the 20-bomb attack. Even with a single detonation, only 45% of the repair area will be accessible to personnel engaged in an 8-hour repair operation if the accumulated dose is to be kept less than 250 roentgens.

Assuming that personnel are completely protected from radiation exposure during transit, a measure of effectiveness for these systems might be the per cent of the repair area that is accessible to repair personnel at various times after attack under the constraint of a total 8-hour dose of less than 250 roentgens. Table 6 shows the per cent of repair area available as a function of time and number of bombs.

It is apparent that under a heavy attack the transit shelter systems do not provide access to an appreciable part of the repair area, even at 12 hours after attack. It was assumed that the repair vehicle was capable of providing complete protection during the transit phase. The entry times will be delayed appreciably if this assumption is not justifiable.

TABLE 6

PER CENT OF ACCESSIBLE REPAIR AREA VS TIME OF ENTRY

Time of Entry	1 Bomb	2 Bombs	5 Bombs	10 Bombs	20 Bombs
H + 1	45%	18%	5%	* < 2%	< 2%
H + 2	93%	36%	10%	4%	2%
H + 4	99%	85%	18%	9%	4%
H + 6	100%	95%	28%	13%	6%
H + 12	100%	100%	88%	23%	10%

REPAIR SYSTEMS PROVIDING SHELTER DURING THE TRANSIT AND THE REPAIR PHASES

Repair vehicle systems that are highly flexible will be capable of reacting rapidly, since their entry into the repair area is not delayed by high radiation levels at the repair sites. Vehicles capable of providing adequate shelter during the transit phase (protection factors greater than 300) should be capable of shielding personnel during the repair phase as soon as H + 1 hour. In general, the lower the protection factor of the vehicle, the slower the reaction time of the repair system. With vehicle protection factors much less than 300, the transit dose becomes appreciable, and the allowable repair dose is reduced accordingly. Either the protection factor must be increased, or the entry time must be delayed.

As was pointed out earlier, there is no known method, at the present time, of protecting personnel engaged in repair work on microwave towers. Tasks such as aligning the reflector mounted on the top of the tower cannot be accomplished within the confines of a vehicle, nor does there appear to be any practical vehicle extension capable of shielding at this distance from the vehicle. Although it is true that elevation provides some attenuation from the fallout on the ground, microwave towers are not high enough to provide attenuation factors of much more than one to two.⁴ The existence of these practically unshelterable repair tasks serves to

⁴U. S. Government Printing Office, "The Effects of Nuclear Weapons" (Washington, D. C. : 1957) p. 437

reduce the flexibility of any proposed repair vehicle, since these tasks could be responsible for delaying the repairs. In fact, if unshelterable repairs are a major part of the total repair agenda, the effectiveness of these repair systems is no better than the effectiveness of the transit shelter systems described previously, because the reaction time in this case will be determined by the radiation level at the repair site.

SPECIAL VEHICLES FOR SELECTED REPAIR SITUATIONS

It is extremely important for the repair system to be augmented by an adequate reconnaissance capability. Accurate definition of radiation levels is essential if early entry times are to be achieved. The need for this capability may be illustrated by the case of unshelterable repairs on microwave towers. It is probable that a tower may be located in a relatively low radiation field. If this information is available, a high velocity transport vehicle (such as a helicopter) might be used to bring personnel to and from the repair site. The transport vehicle would absorb little radiation in transit and could be used for conveying personnel to repair sites where the radiation levels were on the order of 140 roentgens/hr or less at $H + 1$ hour. This procedure would enable personnel to work an 8-hour shift at repair sites where the radiation levels were less than 140 roentgens/hr at $H + 1$ hour, without accumulating more than 250 roentgens.

The speed of the transport vehicle becomes important when a repair task of short duration is to be made in a high radiation field. In general, an adequate reconnaissance capability coupled with a high-speed transport vehicle can improve appreciably the reaction time of the repair system.

Table 7 summarizes the reaction times and flexibilities of all of the proposed repair systems.

TABLE 7
REACTION TIMES AND FLEXIBILITY CHARACTERISTICS FOR THE PROPOSED
REPAIR VEHICLE SYSTEMS

REPAIR VEHICLE SYSTEM	REACTION TIME	FLEXIBILITY
<u>Transit and Repair</u> Truck - Shelter Factor < 300 Truck - Shelter Factor > 300	Entry not possible at H + 1 hour Entry possible at H + 1 hour for entire repair area	Essentially no flexibility Adequate flexibility for all but unshelterable repairs
<u>Transit Only</u> Truck - Shelter Factor < 300 Truck - Shelter Factor > 300	High radiation levels within the repair area prohibit entry until H + 12 hours for heavy attacks Low flexibility delays entry un- til H + 12 hours for heavy attacks	Essentially no flexibility, since the vehicle provides no more on-the-job protection than ordinary clothing
<u>Transit and Repair - Truck and Helicopter Combination</u> Helicopter (transit only) - Shel- ter Factor = 1 Truck (transit only) - Shelter Factor > 300	Entry possible at H + 1 hour for entire repair area	Addition of helicopter provides highest flexibility of all pro- posed repair systems and is capable of treating all but un- sheltered repairs in high radi- ation fields

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

On the basis of this study we conclude that it is feasible to construct a repair vehicle that is capable of supporting communications repair activities in a large part of the area where bomb damage to communications equipment is expected. Furthermore, in many cases, these repairs can be started as early as one hour after bomb detonation.

SPECIFIC CONCLUSIONS

The major conclusions arrived at as a result of this study are:

1. It is possible to design a repair vehicle capable of providing a radiation protection factor of approximately 300. Such a vehicle is adequate to provide working personnel access to areas that have been contaminated by radiation from as many as 20 weapons of 7 MT yield each.¹
2. The two-man repair vehicle giving both transit and repair shelter appears to be the most practical and effective in view of system flexibility and other operational considerations.
3. The repair vehicle system can be used for most normal repair tasks except those involving equipment located at microwave towers. It does not appear technically feasible to protect personnel who must climb towers.
4. The radiation instrumentation required is as follows:
 - a) Total dose meter (dosimeter) for each repairman

¹The value of 300 is not to be construed as the recommended value. The specific value recommended for a design must be determined by further operational analysis and systems design. It should be as large as possible to maximize the vehicle's flexibility while being consistent with other considerations of vehicle design such as speed, range, and terrain traversing capability. This study's assumptions of the fallout magnitude and the protection factor were deliberately very conservative; a more realistic and detailed systems study, therefore, could only serve to substantiate the general conclusion that the vehicle is feasible.

- b) Dose rate meter for each repairman
- c) Dose rate meters for the interior and the exterior of the vehicle
- d) A device for computing and displaying the safe-time-in-activity.

In addition to the major conclusions given above, there are several minor conclusions that are worth listing, even though they are not directly supported by the study:

1. Garages should have a quick vehicle decontamination capability to minimize the vehicle turn-around time.
2. Garages should be located at places that are likely to provide:
 - a) Minimum dose to personnel within the structure
 - b) Minimum dose to personnel enroute to repair
 - c) Minimum probability of blast destruction.
3. Garages should provide a large amount of protection in order that repair personnel can live virtually unaffected by additional radiation after they have received a dose during repair.
4. Consideration should be given to arranging quick connections for splicing together cables, which might be used as jumpers around areas of extensive damage.

RECOMMENDATIONS FOR FURTHER WORK

This study has demonstrated the feasibility of using shielded repair vehicles to accomplish repairs to communication links. Further work is now required in operations analysis and system engineering to determine the specific requirements for a technically and economically satisfactory system.

As a result of this study, it can be seen that the operational capability of a repair vehicle is affected by many factors, some of which are controllable and some of which are not controllable. The most important of the controllable factors are:

1. The location of repair vehicle depots
2. The adequacy of damage reconnaissance and vehicle dispatching procedures

3. The adequacy of personnel training
4. The advance planning of repair procedures and emergency supply stores.

Among the factors that generally cannot be controlled are:

1. The number, placement, and timing of the attacking weapons
2. The production of radiation hot-spots by precipitation, topography, and man-made objects
3. Road congestion and damage.

These factors must be taken into consideration both in the design of a repair vehicle and in the planning of operational procedures for such a vehicle. The controllable factors require further study, and an analysis must be made of the effect of varying the quantities over which the planner has control, to arrive at a vehicle design and operational plans that cope most effectively with a number of possible combinations of the uncontrollable factors. It is felt that these factors should be analyzed in more detail than was possible in this study.

Thus, it is recommended that the following additional studies be made:

1. An analysis of the damage assessment problem, to determine: a) the methods that should be used in locating damage, including methods such as the use of remote indicators in switching centers and reconnaissance by helicopters or other vehicles, b) the extent to which the repair vehicles should be used for reconnaissance, c) the accuracy with which the location and the nature of the damage can be determined, and d) the time required for performing damage assessment.
2. An analysis of the problems involved in providing garages for vehicles, to determine: a) the number and the locations of garages relative to areas of expected damage, b) the amount of blast and fallout protection required by the garages, c) the functional requirements of garages for living facilities, vehicle maintenance and servicing, decontamination, communications, and cable and equipment storage.

3. An analysis of the functional requirements of the repair vehicles in such areas as: a) visibility, b) terrain traversing capability, c) facilities for accomplishing repair tasks within the vehicle, and d) self-decontamination capability.
4. A study to obtain empirical data on attenuation factors of specific vehicles through the use of scale models of vehicles and physical simulation of fallout radiation.
5. An investigation of methods of restoring microwave communications through the use of temporary measures such as spare, retractable towers and highly mobile replacements for microwave equipment, e. g. , balloon-supported antennae.

APPENDIX A
BACKGROUND INFORMATION ON FALLOUT

This Appendix contains background material relating to:

1. Factors influencing fallout
2. Assumptions involved in the Tech/Ops fallout model
3. Differences between instantaneous dose rates and
cumulative doses
4. Human tolerance to radiation.

APPENDIX A
BACKGROUND INFORMATION ON FALLOUT

FACTORS INFLUENCING FALLOUT

WEAPON TYPE

Nuclear weapons are characterized by two parameters: (1) weapon yield, or size, and (2) the per cent of the yield attributable to fissionable material. The size of the crater formed by the weapon is determined by the weapon size, which determines also the size of the fireball and the altitude to which the fireball rises (all other conditions being the same). The size and altitude of the fireball, in turn, determine the cloud height and its physical dimensions, which, in turn, influence the particle deposition. Thus, in a consideration of deposition patterns, variation in yield or weapon size has a primary effect on the geographic distribution of the fallout particles.

The amount of radioactivity in the cloud is directly dependent upon the amount of fissionable material in the bomb. Therefore, the amount of fissionable material in the bomb influences intensity levels within the geographic distribution of the particles.

PARTICLE SIZE DISTRIBUTION IN CLOUD

Radioactive particles are distributed throughout the cloud, but the very heavy particles remain in the stem rather than rising as far as the cloud. Fallout particles have been found to have diameters ranging from 10 to 2000 μ (microns). These particles, at the instant of stabilization, are in the cloud. Later they fall to the ground under the influence of gravitational and meteorological forces. The particle size distribution within the cloud influences the fallout levels at downwind points, because particles issuing from various altitudes terminate their fall paths at different points downwind.

WIND FIELD FROM TOP OF CLOUD TO GROUND

The wind speed and direction are not, in general, constant from the top of the cloud to the ground. This variation in the wind field affects fallout levels downwind,

because the particles are acted upon by the wind currents at the different altitudes through which they fall.

RADIOACTIVITY ASSOCIATED WITH DIFFERENT PARTICLE SIZES

Although fallout particles have been found with diameters ranging from 10 to 2000 μ , the bulk of the radioactivity is carried by particles in the range of 50 to 500 μ .¹ Because larger particles fall more rapidly than smaller particles, the particle size activity distribution has an important influence on the distribution of fallout on the ground.

ASSUMPTIONS INVOLVED IN THE TECH/OPS FALLOUT MODEL

Before discussing the actual fallout model used in this study and the way in which the factors influencing fallout are taken into consideration, some mention should be made of the problems that arise in constructing a fallout model due to the lack of detailed experimental data. The scarcity of data is evident particularly in the case of megaton-size weapons; all fallout models proposed by various agencies during the past several years have been hampered because of this. Consequently, the fallout model must be based on a number of plausible assumptions. In addition, it is desirable to make further assumptions in order to simplify the computations so that they can be carried out without recourse to a digital computer.

The needed assumptions are discussed in the Tech/Ops report, "The Probable Fallout Threat Over the Continental United States."² Only a brief outline of these assumptions is presented here; the reader is requested to refer to the document for a further explanation. Since there are two reasons for making assumptions—the absence of experimental data and the simplification of the calculations—they will be listed under these two categories.

Assumptions Made Because of the Absence of Experimental Data

1. The instant of stabilization is considered to be ten minutes after weapon burst for all megaton-size weapons.

¹E. Callahan, et al., "The Probable Fallout Threat Over the Continental United States," Technical Operations, Inc., Report No. TO-B 60-13 (1 December 1960) p. 98.

²Op. cit.

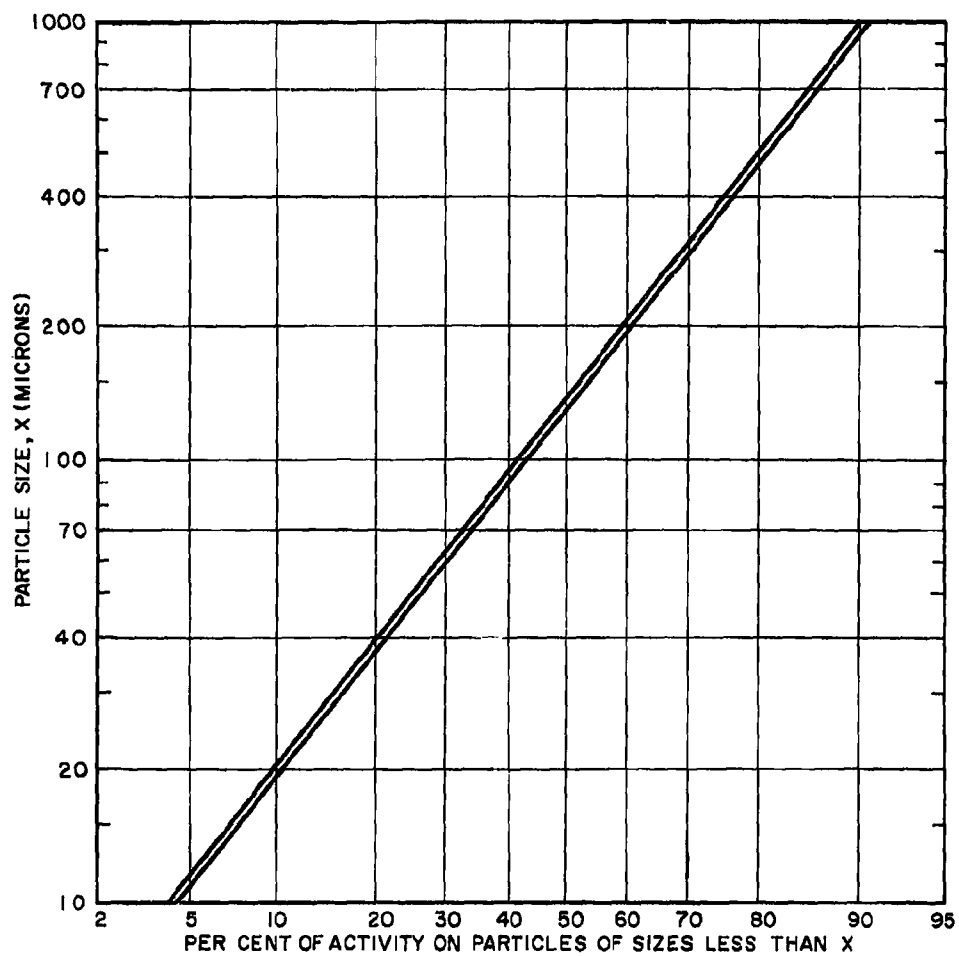
2. The radioactivity in the cloud is distributed lognormally with respect to particle size, as shown in Figure A-1.
3. The radioactivity per unit volume decreases with increasing altitude in proportion to the decrease in air density.
4. The particles have the shape of irregular spheres.
5. In any horizontal cross section of the cloud, the activity per unit area is constant.

Assumptions Made to Simplify Calculations

1. The horizontal wind pattern that exists over ground zero at the time of the weapon burst does not change greatly during the fallout process.
2. There are no vertical wind currents.
3. The cloud has the shape of an inverted truncated cone at the instant of stabilization.
4. Particles within the stem of the cloud do not contribute significantly to the total fallout. (Particles from the stem tend to land very close to ground zero, where blast damage and other immediate effects are more severe. Also, it is estimated that the stem contains less than 10% of the total activity.)
5. The total amount of fallout that might land at any point after a nuclear attack is likely to be the result of more than one nuclear weapon. However, there are no experimental data on multiple weapon detonations. Consequently, the fallout model is based on a single burst. In the case of multiple weapons, we have assumed that the fallout effects of several bombs are additive — i. e. , the dose rate contours can be added at any point at which the contours obtained from several weapons overlap.

DIFFERENCES BETWEEN INSTANTANEOUS DOSE RATES AND CUMULATIVE DOSES

For the purpose of this study, a fallout model was constructed that accounts for the effects of wind, particle size distribution, weapon size, etc. , by an



(Based on data taken by the Naval Radiological Defense Laboratory)

Figure A-1. Activity Distribution by Particle Size

integrating process using appropriate cloud volume subdivisions. This model will be discussed in detail in a forthcoming report, and the discussion will not be repeated here. The output of this model is a set of contours of instantaneous dose rates, which indicate the rate at which radiation doses would be received by unsheltered persons.³ Instantaneous dose rates are expressed in roentgens per hour.

Due to the decay of the particle radioactivity, dose rates are not constant over periods of time, even if all particles have arrived on the ground. For example, an instantaneous dose rate of 400 r/hr (roentgens/hour) at one hour after weapon burst will not be 400 r/hr at two hours, but will have decayed to a different value.⁴ Thus, it is necessary to time-tag the instantaneous dose rates (i. e., to speak of x r/hr at y hours) in order for the rates to have any meaning.

It can be seen, then, that an instantaneous dose rate cannot be converted to a total radiation dose by simply multiplying by the time of exposure. When computing a radiation dose at a particular point or within a certain area, it is necessary to integrate the instantaneous dose rate over the desired period of time.

HUMAN TOLERANCE TO RADIATION--

NUCLEAR RADIATION EFFECTS WITHIN ONE TO TWO DAYS AFTER DOSE

The restoration of communication facilities following a nuclear attack requires the ability of the repair teams to perform the necessary actions within one to two days immediately after the attack. During the period of time from one to two days after the receipt of an acute dose,⁵ the symptoms of radiation sickness are manifested by nausea and vomiting. Shortly thereafter, fatigue takes effect, followed by an indeterminate period during which the eventual death or gradual recovery is determined, depending upon the magnitude of the dose. Table 2 (p.13) is based on the results of animal experiments as well as on conclusions drawn from observations made of the individuals exposed in Japan and on the Marshall Islands.

³U. S. Government Printing Office, "Nature of Radioactive Fallout and Its Effects on Man" (Washington, D. C. : 1958) Part I, II p. 779, p. 794.

⁴Providing that no additional radioactivity has arrived in the vicinity of the point of measurement in the meantime.

⁵A dose received over a short period of time.

The severity of radiation sickness and the probability of death occurring within one to two months after the attack will be determined within the first two to four days of exposure.⁶ Additional exposure to radiation after this initial period will not affect the recoverable portion of the injury, because the decline of the effective dose or net injury after about four days indicates that the recoverable portion of the injury is being repaired more rapidly than the rate of additional injury, due to continuing exposure to fission products undergoing radioactive decay.

A chronological summary of the clinical symptoms of radiation sickness of three degrees of severity is given in Table 3 (p. 14). Further data gathered from several peacetime nuclear accidents are summarized in Table 4 (p. 15).

RECOVERY RATE AND IRREPARABLE INJURY

Recuperation from radiation injury is expressed in terms of the amount of time required to achieve a given level of recovery. A level of 50 per cent recovery has been arbitrarily chosen, and the amount of time required for a 50 per cent recovery has been named the recovery half-life. Recovery half-lives have been experimentally determined for mice, rats, guinea pigs, dogs, and burros. Strong evidence has been found to indicate that the response of man to irradiation is qualitatively similar to that of various animals.

A certain amount of empirical evidence has been gathered on the response of individuals to various levels of radiation exposure. One of the best single indices of radiation sickness in man is the number of white blood cells in the blood stream. "Of the portions of the body that are accessible for examination, circulating blood is the one which is affected the earliest and the most profoundly by large amounts of ionizing radiation. It is, therefore, a sensitive and easily studied gauge not only of the severity of the effects of radiation but also of the character and degree of recovery."⁷

⁶J. F. Batter, E. D. Callahan, E. T. Clarke, and P. I. Richards, "Time Scheduling for Emergency Operations in a Fallout Environment," Technical Operations, Incorporated, Report No. TO-B 59-15 (7 January 1960) p. 9.

⁷Joint Commission for the Investigation of the Effects of the Atomic Bomb on Japan, "Medical Effects of Atomic Bomb," Army Institute of Pathology (19 April 1951).

The white blood count response in man provides a reasonable check against the recovery half-life extrapolation determined from the various animal experiments and indicates that the recovery half-life of man is approximately 25-35 days.

The irreparable injury results in the lowering of the effective median lethal dose (450 r) for subsequent exposures to radiation after the time when the recovery process should have been substantially completed. There is a general consensus as to the existence of a permanent effect,⁸ although no agreement has been reached as to whether the effect is constant, varies with the dose rate, or varies with the magnitude of the total dose.

LONG TERM NUCLEAR RADIATION EFFECTS

The long term effects of nuclear radiation, such as genetic effects, cataracts, and leukemia, may not appear for some years after exposure. Examination of Japanese victims revealed that patients suffering from cataracts and leukemia as a result of the respective explosions were within one mile of ground zero and must have received doses approaching the median lethal value of 450 roentgens.

The following remarks are taken from a Tech/Ops report prepared for the Office of Civil and Defense Mobilization, "Summary of Long-Term Biological Effects of Radiation,"⁹ and concern an acute exposure of a large population to about 100 roentgens of whole-body radiation.

"1. The spontaneous gene-mutation rate in exposed individuals would be doubled or tripled. If a birth rate of 100,000,000 per generation is assumed for the United States, a total of about 4,000,000 new, severe genetic defects might appear in future generations, 10% of these probably occurring in the first generation. (This figure of 4,000,000, or 4% of births, is about equal to the per cent of major defects that occur normally in our present population.)

⁸J. S. Krebs, R. W. Brauer, and H. Kalbach, "Analysis of the Non-Recoverable Injury Resulting from X-Irradiation," paper presented before The Radiation Research Society (N. Y., N. Y.: May 1955).

⁹A. L. Kaplan, "Summary of Long-Term Biological Effects of Radiation," Technical Operations, Inc., Report No. TO-B 60-29 (15 May 1961).

"2. The relation between carcinogenesis and radiation exposure dose is not well known. Indications are that a whole-body exposure of about 100 r would at least double the spontaneous production of cancer cells. However, the production by radiation would be more concentrated in both location in the body and in time, making the risk of tumor production considerably more than twice as great from radiation as from spontaneous mutation.

"3. There is not yet general agreement as to whether leukemia incidence is linear with exposure dose. Analysis of a collection of data related to leukemia incidence in various exposed and unexposed population groups yields an order of magnitude of about 20,000 cases of leukemia per year in a population of 100,000,000 people exposed to 100 r of whole-body radiation. This compares with the present normal rate of about 6000 cases per year per 100,000,000 population.

"4. Life-span shortening in man due to the acceleration of aging processes is estimated to be about 5 to 10% per 100 r exposure for exposed individuals of about 20 years of age.

"5. It should be re-emphasized that these conclusions regarding the long-range reactions of man's biological system to a dose of the order of 100 r are based on the assumption that the biological response involved is directly proportional to the radiation exposure dose. Each conclusion, except number three, is based on extrapolations from animal data"

APPENDIX B
A. T. & T. REPAIR VEHICLES

APPENDIX B

A. T. & T. REPAIR VEHICLES

This appendix contains illustrations of three of the vehicles that are currently used by the American Telephone and Telegraph Company (A. T. & T.) for the installation and repair of cables and wires. These illustrations have been included to show the most highly mechanized equipment that is available for emergency repair work. All three vehicles are used by crews of one or two men and allow more rapid construction and repair work than any previously used A. T. & T. vehicles. The approximate sizes of the storage areas for equipment and supplies on the vehicles are apparent from the illustration; they were useful in estimating shielded volume requirements.

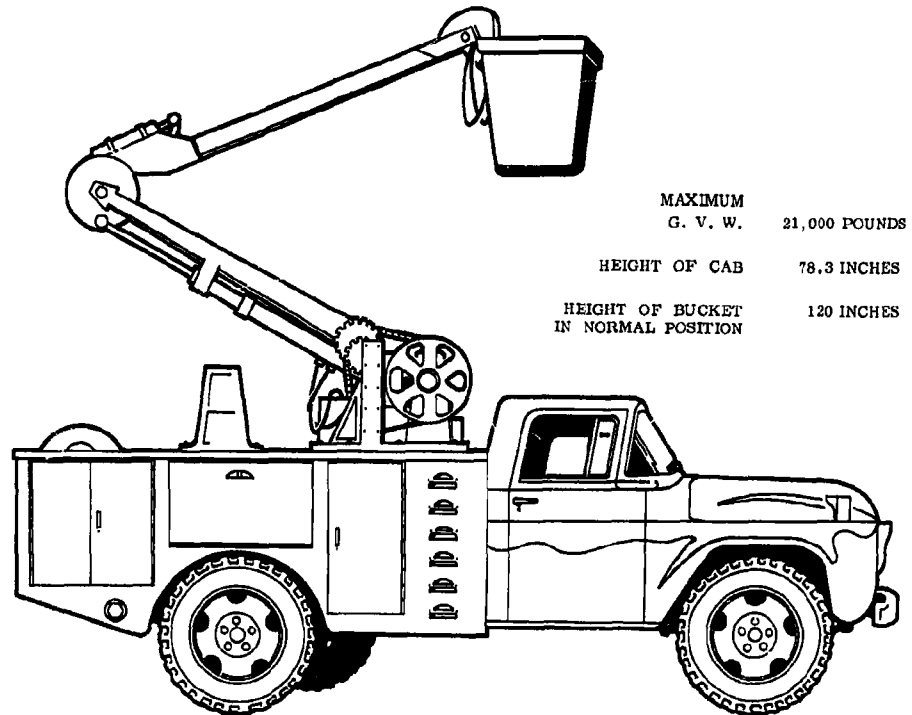


Figure B-1. Cable Stringing Truck

BODY AND LADDER	3,000 POUNDS
CHASSIS AND CAB	4,633 POUNDS
AVERAGE EQUIPMENT	2,570 POUNDS
PAYLOAD AND PERSONNEL	2,797 POUNDS
TOTAL	13,000 POUNDS

WIDTH OF CAB	84 INCHES
HEIGHT OF LADDER IN NORMAL POSITION	116 INCHES

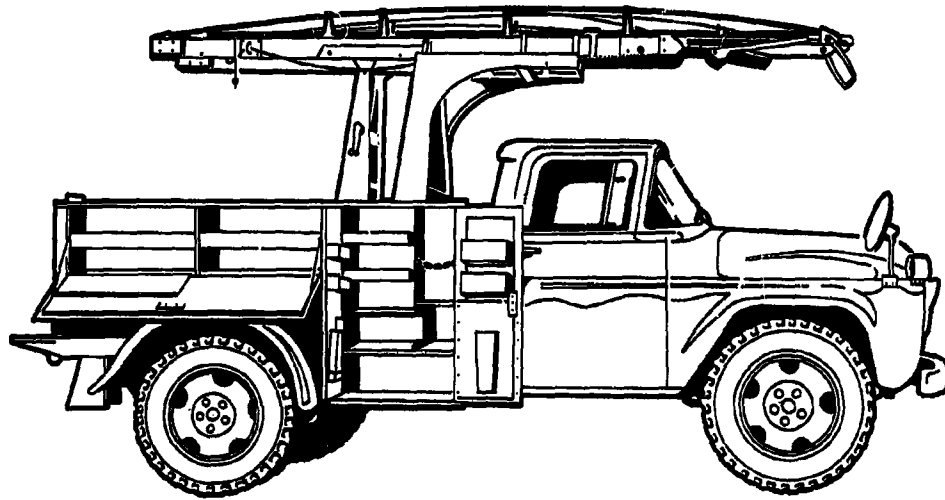


Figure B-2. Aerial-Cable Splicing Truck

CAB	3,700 POUNDS
AVERAGE EQUIPMENT	3,325 POUNDS
CHASSIS AND CAB	5,167 POUNDS
PAYLOAD AND PERSONNEL	5,808 POUNDS
TOTAL	18,000 POUNDS

HEIGHT OF CAB	83 INCHES
HEIGHT OF BODY IN NORMAL POSITION	105 INCHES

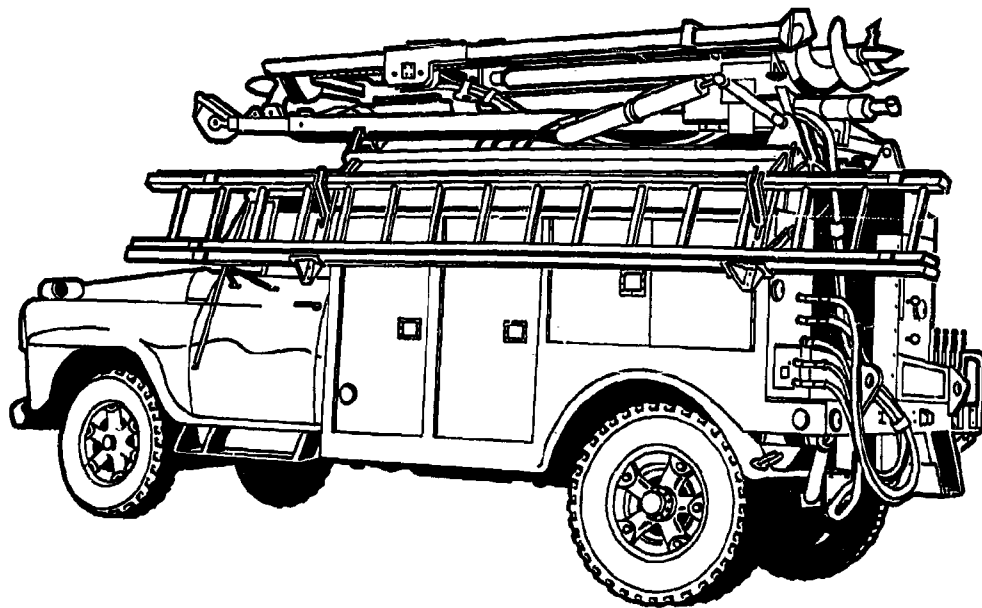


Figure B-3. Pole Setting Truck